JPRS-JST-88-007
17 MAY 1988

FOREIGN
BROADCAST
INFORMATION
SERVICE

JPRS Report

Science & Technology

Japan

8

JPRS-JST-88-007

17 MAY 1988

SCIENCE & TECHNOLOGY

JAPAN

CONTENTS

MICROELECTRONICS

NUCLEAR ENGINEERING

/12223

Ceramics Development Program Discussed

New Technology in 1990's

43067506a Tokyo CERAMICS JAPAN in Japanese Aug 87 pp 632-635

[Article by Hiromu Okazoe, Mitsubishi Research Institute, Inc.: "New Technology (Material Technology) in the 1990's"]

[Text] I. **Changing Social, Economics Needs**

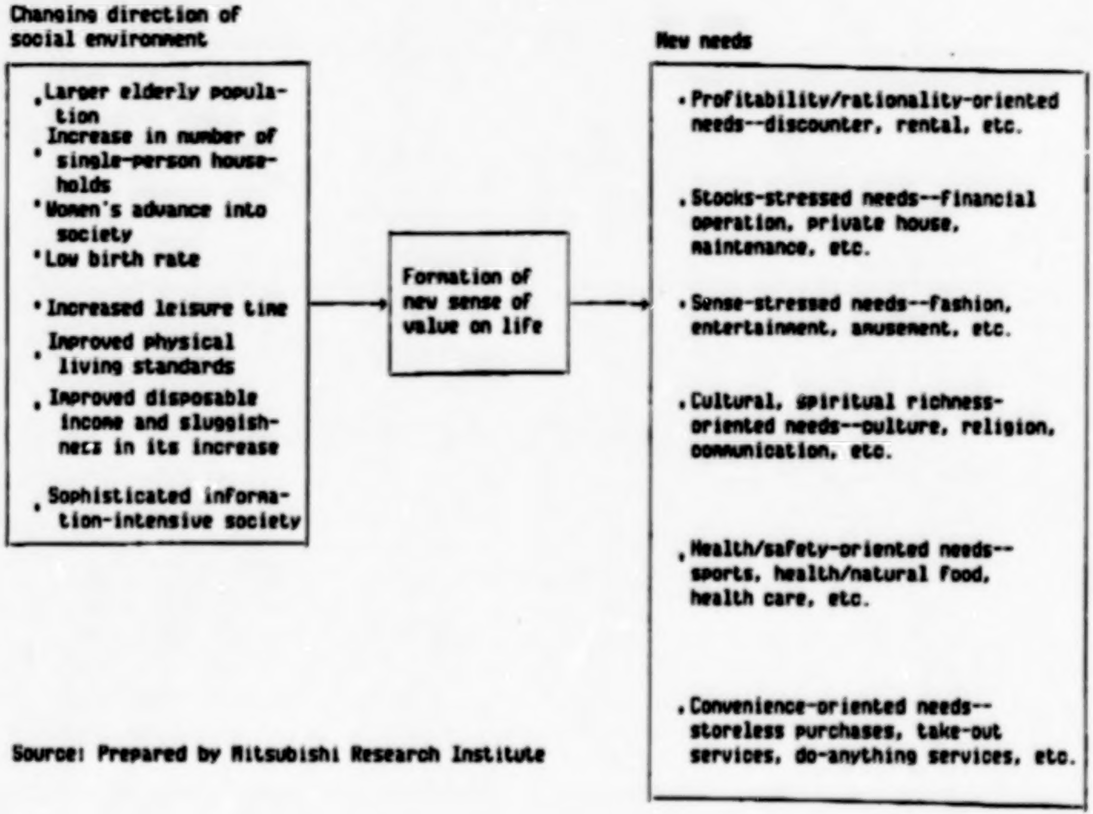
Japan first initiated its ambitious policy of and investment in technological development with its motto "Catch up with and overtake Western developed industrial nations." As a result, as can be see in the recent competitive VTR market and the semiconductor issue between Japan and the United States, Japan's technical level has caught up with those of Western developed industrial nations, thereby resulting in friction in trade and technology.

It an be said that most of the leading technologies in the 1980's have been for the integration and systematization of equipment and electricity by wisely combining new individual technologies such as IC and material technology with automobile manufacturing, electronics product manufacturing, and NC process techniques.

These systematization technologies will, along with the advancement in computer and information/communications technologies in the future, develop into those which will lead the information-intensive society of the 1990's, thus further expanding their importance. Current drastic changes in the social, economic, and technical environment considered, the advent of new technologies having characteristics and functions totally different from those of conventional ones can be expected in the 1990's.

The 1990's will see a further advanced social and economic environment with respect to maturity, internationalization, and information networks.
Table 1 shows new consumer needs responding to future changes in the environment. Those worth watching will attach importance to enriching the mind, such as sports, health, culture, entertainment, etc., instead of quantitative affluence. Parallel to this, also in a technical aspect, the development of products rich in variety, operability and topics, of new

Table 1. Changes in Living Environment of an Aging Society and New Needs



Source: Prepared by Mitsubishi Research Institute

materials and new elements with high functionality or unique functions, and of technologies relevant to their design and high-precision machining will be in strong demand.

II. New Technology Expected in 1990's

Technological progress has been rapid in recent years, such as the development of high-temperature superconductive ceramic materials often reported in newspapers and of high integration technology related to the progress in semiconductors. This trend is expected to continue in the future. Table 2 shows a summary of important technologies very likely to appear in the 1990s compiled from a technical forecast made by the Mitsubishi Research Institute. The following are descriptions of the result.

1. New Materials--Metallic, Organic/Inorganic Materials

In the 1990's there will be great interest in metallic materials such as an ultraplastic alloy, hydrogen-stored alloy, high-performance crystal control alloy, and extra heat resistant alloy. As for their appearance, the ultraplastic alloy will be put to practical use first between 1988-1992,

Table 2. Technical Forecast on New Materials and New Elements
(Source: Prepared by Mitsubishi Research Institute)

	Theme	Date (1985 1990 1995 2000)
Metal	1. Metallic structural materials with ultraplasticity to be put to practical use.	
Metal	2. Hydrogen-stored alloys with hydrogen-balanced pressure below 10 atm and occluding 200 ccNTP hydrogen/1cm³ metal utilized	
Metal	3. High-performance crystal control alloys able to conduct forming operation, control metallic morphology put to use, based on alloy design.	
Metal	4. Heat resistant alloys able to withstand load of 15 kgf/mm² for over 1,000 hr at high temperature of 1,300°C.	
Ceramics	5. Superconductive materials with critical temperatures above liquid nitrogen (77K) will be used for electric machines in industries.	
Ceramics	6. FRM able to withstand harsh, ultimate conditions (space development, atomic energy) put to practical use.	
Ceramics	7. Method of stably synthesizing diamond thin films put to practical use.	
Ceramics	8. Computerized material design technology for ceramics with desired composition, structure, and properties put to use.	
Organic Material	9. Polymeric materials with electric conductivity as high as silver developed.	
Organic Material	10. Organic photochromic materials which allow optical absorption spectrum to change reversibly by illumination put to use.	
Organic Material	11. Engineering plastics with heat resistant temperatures over 400°C developed.	
Organic Material	12. Polymer batteries put to practical use for automobiles or solar cells.	
Element	13. Compound semiconductor logical elements (GaAs) with high switch speeds below 10 ps put to practical use.	
Element	14. Ultrahigh-speed high-integrated elements laminating logical, memory elements in multilayers put to practicla use.	
Element	15. OICs, circuits with multiple optical elements highly integrated on same substrate, put to practical use.	
Element	16. Memories (100GB/cm²) with high-integrated recording density by photochemical burning (PHB) to be developed.	
Element	17. Image processor with 3-dimensional IC photoelectric transfer elements on surface, signal processing function inside, to be put to practical use.	
Element	18. High-integrated biomolecular sensors to be put to practical use.	
Element	19. Recording vast quantity of information (1TB/cm²) on molecular level and prompt reading technology to be developed.	
Element	20. Luminescent elements able to emit visible radiation with any color by electric signals to be put to practical use.	
Machining technology/Misc.	21. Technology for mass manufacturing 10–100Å metallic ultraparticles at low cost to be developed.	
Machining technology/Misc.	22. Machining technology will be used for elements with memory function of 1 GB/chip (ion beams applied).	
Machining technology/Misc.	23. Ceramics forming technology by HIP permitting continuous processing to be put to practical use.	
Machining technology/Misc.	24. Material synthesizing technology using lasers to be put to practical use.	
Machining technology/Misc.	25. Technology for controlling more than one coupling method on atomic level, synthesizing new materials to be developed.	
Machining technology/Misc.	26. Test method, standardization for characteristics evaluation data on fine ceramics of complex shapes put to practical use.	

followed by the development of an extra heat resistant alloy capable of being used in specific environmental conditions between 1996-2002. As to the development of metallic materials, key technologies are crystal grain control (ultraplastic alloy) and metallic powder surface control (hydrogen-stored alloy) technologies, and database and reliability evaluation technologies.

With regard to inorganic materials, expectations are placed on the development of technologies for superconductive ceramics materials that have recently gained much attention--FRM for use in space and atomic energy, diamond thin films, and material design. The "synthesis of stable diamond thin films" will materialize first around 1988-1995, with the rest forecast to appear after 1995. The application of superconductive ceramics materials to electric machines is also expected around 1994 at the earliest. Those selected as key technologies for practical use are:

Superconductive ceramics materials: Technologies for wire rod and mass production.

FRM for use in space and atomic energy: Interface control technology for fibers and matrixes, process and reliability evaluation technology.

Diamond thin film: Technologies for low-temperature film manufacturing and creation of plasma with good producibility.

As for organic materials, there is great interest in the development of materials with sophisticated or unique functions. The development of conductive polymeric materials, organic photochromic materials, extra heat resistant plastics, and polymer batteries are also drawing much attention.

Conductive polymers include conjugate polymers such as polyacetylene and polythiazile, organic complex, organic metallic complex, and graphite materials with their use ranging widely from lightweight electric wire to circuit, wire bonding, secondary cell, and shielding agent. Thus, their practical use as substitutes for metallic materials is likely to result in a great impact on industry and society. The forecast places expectations on their applications to cells and electric circuits from 1995 at the earliest and practical use of molecular elements from 2000.

Photochromic materials are expected to be applied to switching elements and molecular elements with their practical use likely between 1992-1995.

With regard to heat resistant plastics, those capable of withstanding temperatures as high as 300°C, such as polyimide and polyamidoimide have already been developed, while the development of those withstanding over 400°C is likely to occur around 1990.

A polymer battery is expected for use in automobiles and electric power because of characteristics which are absent in conventional batteries, such as light weight, flexibility and high power. Currently, it is still small in capacity with its charge and discharge conducted at low current density.

Its application is likely around 1994-1995. Material stabilizing technology as well as the development of technology for further improving characteristics of individual materials is playing an important role n their development.

2. Elements

As for elements, the development of technologies will center around high integration, higher density, high-speed operation and read, and optical applications. This trend is reflected in the themes in Table 2. The application of the elements whose target is developing their machining technologies, according to the table, should be in the first half of the 1990's, and for optical elements whose target is developing materials from 1995. Key points for developing these elements are sophistication of ultraprecision/hyperfine machining and thin film creating technologies such as the LB, MBE, and MOCVD methods.

3. Machining Technologies and Miscellaneous

When new materials and new elements reach the present level of sophistication and ultraprecision, peripheral technologies related to their manufacturing also become sophisticated and ultraprecise. Above all, the technology for manufacturing materials and hyperfine machining using lasers and ion plasma can be regarded as important. Figure 1 shows their relation.

(1) Laser Technology

Cutting metals and trimming IC circuits have been simplified by CO_2 lasers and solid lasers (YAG). However, what is required for the development of elements in the future is hyperfine (below 1 μm) processing, thus necessitating the development of new lasers different from those above. An excimer laser with a short wavelength and high output and a free electron laser capable of freely controlling its wavelength have recently been developed and put to practical use, thus compensating the disadvantages of the CO_2 and YAG laser. These lasers utilize the advantages of high energy beams and can permit selective chemical reactions by direct irradiation or beam induction and synthesis and reforming of high-grade, homogeneous materials. In such cases, lasers utilize photochemical reactions so that treatment is done with a low temperature process entirely different from the conventional high temperature/heat treatment process, raising expectations for their wide range of applications such as processing and surface treatment of materials vulnerable to heat, thin film formation, and selective cutting of atoms and radicals in polymers and molecules (quantum cutting). Application of these "material synthesizing technologies using lasers" are expected between 1991-1994.

(2) Ion/Plasma Technologies

Ion/plasma technologies are regarded as key technologies for developing new materials, such as ultrathin film, hyperfine grain, and amorphous

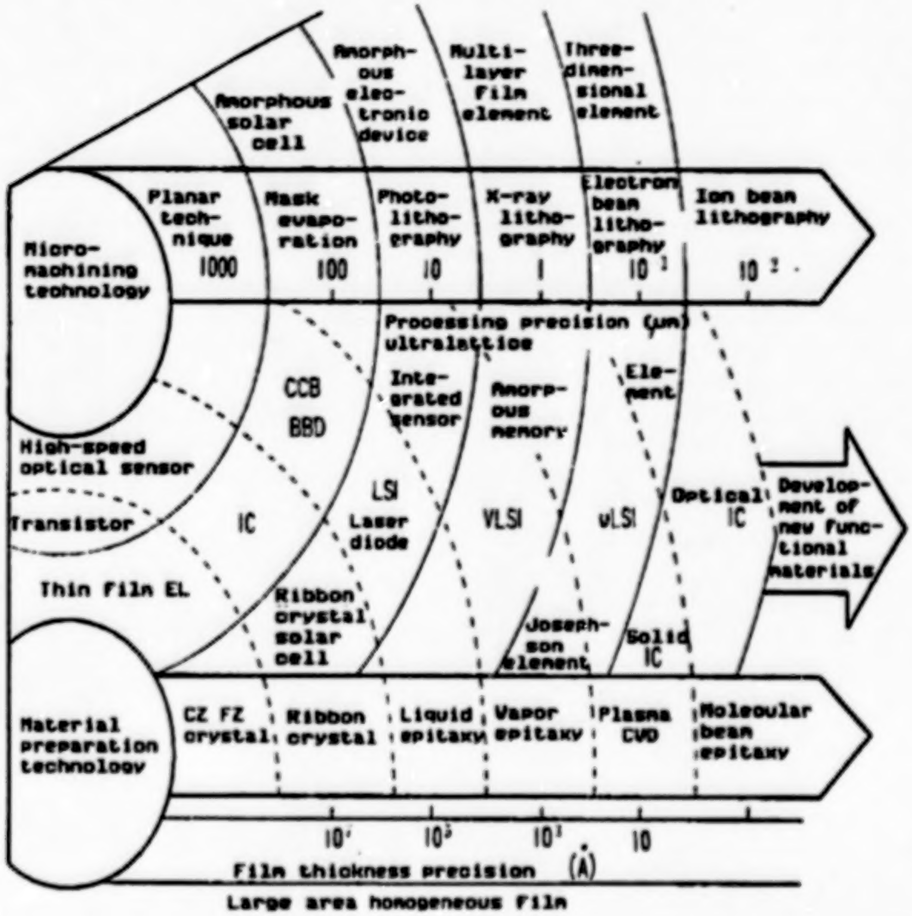


Figure 1. Birth of New Functional Elements by Advanced Micromachining and Material Technologies
(Source: Yoshihiro Hamakawa, Engineering Department, Osaka University, NIKKAN KOGYO, 24 April 1987)

semiconductors, and highly functional items, such as superlattice and laminated film which are combinations of these new materials, that will help lead the 1990's. As is the case with lasers, these technologies permit, besides hyperfine machining by focusing of beams, synthesizing (low temperature process) materials difficult to manufacture in a thermal equilibrium state, and synthesizing laminated matters of different types by fully controlling atomic/molecular levels. Currently amorphous silicon solar cells and diamond thin films are manufactured by sputter evaporation, ion plating and plasma CVD using ion/plasma technologies. In the future, developments and applications will be made of hyperfine machining, for example, "machining of elements having a memory function of 1 GB/chip" and new synthesizing technology utilizing ion clusters with their application predicted in the latter half of the 1990's.

As stated so far, the development of hard science is indispensable for synthesizing new materials, while parallel to this, the development of soft

science such as creating a database for material design and computer simulation to show new material synthesizing methods is also considered important. Its application is predicted in the latter half of the 1990's.

III. Conclusion

The above descriptions are of material technologies whose applications are expected in the 1990's. Their development will, more than in the 1980's, center around technologies for special environments and microenvironments, such as higher integration and higher density, ultraautomization, ultrahigh/ultralow temperatures, and synthesizing matters with atomic/molecular-level control. In the 1980's technical development has centered around hardware, while in the 1990's the development and readjustment of software technology aimed at improving the efficiency and diversification of technical development and the development of hardware technology, are expected to become important themes.

Reorganization of Industrial Base

43067506a Tokyo CERAMICS JAPAN in Japanese Aug 87 pp 636-642

[Article by Ikuo Tomita, MITI: "Administrative Policy in the Field of Fine Ceramics in Japan"]

[Text] I. Introduction

The Fine Ceramics Office, MITI, is initiating its policy of reorganizing the industrial base and furthering technical development in order to contribute to the smooth progress in fine ceramics which have a great number of superior functions and characteristics and are regarded as the key to the development of pioneer industries.

The following are descriptions of MITI's fine ceramics policy in FY 1987 and future objectives (Table 1).

Table 1. List of Budgets Related to Fine Ceramics

(Unit: thousands of yen)

Item	FY 86 budget	FY 87 budget
Consumer Goods Industries Bureau		
1. Fine ceramics industry policy expenses	14,854	14,015
(1) Trend research on fine ceramics industry	2,813	2,813
(2) Operation of Fine Ceramics Basic Problem Council	3,437	3,458
(a) Ministry	2,768	2,791

[continued]

[Continuation of Table 1]

Item		FY 86 budget	FY 87 budget
(b)	International Trade Policy Bureau and Industrial Policy Bureau	669	667
(3)	Research commission cost for the fine ceramics industry	8,604	7,744
(a)	Research cost by material and problem	2,933	2,933
(b)	Research cost for international cooperation on fine ceramics	5,671	4,811
Other Bureaus			
1.	Research commission cost for fine ceramics standardization	14,263	16,050
2.	Fine ceramics (next generation)	972,256	1,201,586
3.	Comprehensive recycled water application system (large project)	(1,071,590)	(2,122,514)
	(fine ceramics separating film)	193,600	
4.	Ultrafrontier machining system (large project)	(20,000)	(1,099,331)
	(diamond coating)	--	
5.	Fuel battery generating technology (moonlight)	(3,189,553)	(3,383,226)
	(battery material)	74,000	32,500
6.	Collaboration between government and private sector (research institutes)	(225,600)	(313,288)
(1)	Ultraplastic ceramics	28,947	Undecided
(2)	High-function medical materials	40,481	Undecided
7.	R&D of conductive inorganic compounds (industrial revitalization subsidies)	80,636	78,880
8.	Technical development for petroleum alternative energy by the Small Business Corp.	(465,500)	(427,000)
	(ceramics heat exchangers for high-temperature exhaust gas from industrial furnaces)	--	Undecided

[continued]

[Continuation of Table 1]

Item	FY 86 budget	FY 87 budget
9. Development and demonstration test costs for inspection-free equipment (cost for development of high technology for light-water reactors, etc., within demonstration test commission costs for light-water reactor improving technology)	(1,360,189) 22,749	(1,848,153) 28,949
10. Development of technology for petroleum production under high-temperature corrosion resistant environment	(552,000 3,000	(659,928) Undecided
11. Readjustment and promotion of database and information supply service (fine ceramics)	(66,000) 15,970	--

II. Reorganization of Industrial Base

1. Readjustment of Statistics

The readjustment of statistics for fine ceramics production, etc., is indispensable for grasping the situation of the fine ceramics industry and thereby contributing to various national policies. Dynamic statistics research based on the Statistics Law on fine ceramics production has been newly conducted by the Research and Statistics Department, MITI, since January 1986. The results of the research are announced in a monthly report on general merchandise every month. The total sales of fine ceramic parts and materials in 1986, including quartz resonators, thermistors, varistors, magnetic materials, and diamond, which are separately reported in monthly reports on mechanical statistics, amount to about ¥656 billion. About three-fourths (76 percent) of the sales are of functional materials, a large portion of which are occupied by condensers, IC packages, and magnetic materials, while a large portion of those of structural materials are occupied by diamond machine tools. Figures 1 and 2 show monthly transitions of sales of functional and structural materials, respectively.

The statistics of fine ceramics parts and materials started only a year ago, and analysis and evaluation of their result need to be made on the basis of long-term trends. They are expected to gradually permit the future analysis of production trends of the previous year, etc., based on the hitherto research results.

2. Promoting Industrial Standardization

For the smooth diffusion and progress of fine ceramics, it is necessary to establish evaluation test methods to obtain basic data needed for designing

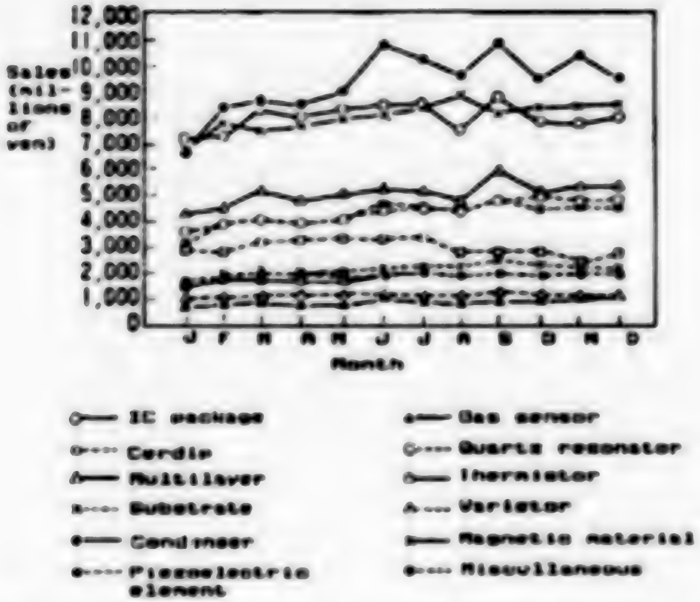


Figure 1. Dynamic Drawing of Monthly Sales of Fine Ceramics Functional Materials (1986)

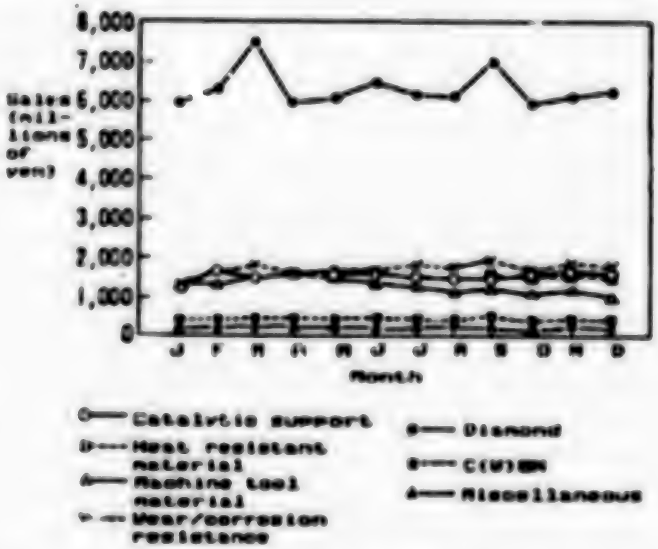


Figure 2. Dynamic Drawing of Monthly Sales of Fine Ceramics Structural Materials (1986)

and manufacturing fine ceramic materials and standardize them (incorporating them into the JIS--Japanese Industrial Standard). To this end, MITI has consigned "research on fine ceramics standardization" to the Japan Fine Ceramics Association since FY 1983, where the formulation of the draft proposal of the basic plan for their standardization and various evaluation tests in line with the draft proposal have been underway.

The cold bending strength test method (JIS R-1601) and elastic modulus test method (JIS R-1602) have already been standardized under the JIS as fine ceramic method standards. With regard to "chemical analysis method for fine ceramic material silicon nitride," a draft proposal for incorporating technology into the JIS has been presented and is scheduled to be enacted.

The following are the candidate 11 items selected to be soon incorporated into the JIS in the basic plan for the furtherance of fine ceramics standardization: 1) hot bending strength; 2) tensile strength; 3) fracture toughness; 4) hot elastic modulus; 5) Poisson's ratio; 6) oxidation resistance; 7) corrosion resistance; 8) creep strength; 9) heat conductivity; 10) specific heat; and 11) compressive strength.

Table 2 shows their research implementation program by fiscal year. The research on hot bending strength was completed in FY 1985 followed by continuous research in FY 1986 on tensile strength, fracture toughness, hot elastic modulus, and Poisson's ratio and research on newly added oxidation was completed in FY 1985, a draft proposal to incorporate it into the JIS was prepared based on research reports by the Japan Fine Ceramics Association commissioned by the Agency of Industrial Science and Technology (AIST).

Table 2. Yearly Research Implementation Program on Fine Ceramics Standardization (to the JIS)

Item	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88
(Preparation of the basic program for fine ceramics standardization)	———	———→				
1. Hot bending strength	———	———	———→			
2. Tensile strength		———	———	———→		
3. Fracture toughness		———	———	———→		
4. Hot elastic modulus			———	———→		
5. Poisson's ratio			———	———→		
6. Oxidation resistance				———	———→	
7. Corrosion resistance					———	———→
8. Creep strength					———	———→
9. Heat conductivity					———	———→
10. Specific heat					———	———→
11. Compressive strength					———	———→
Research budget (thousands of yen)	5,248	12,802	16,209	14,263	16,050	

Since the application of ceramics to diesel engine eddy current chambers and turbo charger rotors have been making rapid headway in recent years, the quick, strong establishment of more proper standardization is desired. MITI is scheduled to move forward with their standardization more energetically in order to contribute to the smooth development of fine ceramics which have started to be used as structural materials.

Besides the 11 items listed in the basic program, standardization is desired, for example, for wear resistance, hardness, thermal shock resistance, and coefficient of thermal expansion, and their standardization will also be studied accordingly.

3. Readjustment of Database

At present most fine ceramics are used in a limited number of fields such as electronic parts and a great number of fields are still in their R&D stage.

For a wider range of applications of fine ceramics as an industrial material, it is urgent to make efforts to readjust the database system on fine ceramics as well as efficiently advance their R&D, expand applications, unify test and evaluation methods for product diffusion and standardize materials and parts.

Japanese databases lag behind those of Western nations and those on frontier materials such as fine ceramics, in particular, have not been readjusted yet. In this context, MITI has consigned "research on the fine ceramics database system" to the Fine Ceramics Center since FY 1985 and studied an ideal database on the basis of research on needs at home and abroad. In FY 1986, it conducted studies of data processing methods, system functions and operation forms for entire system designs and experimentally prepared a thesaurus for fine ceramics. Incidentally, the expected database is a combination of a retrieval system for literature and information and a fact database (material performance database) aimed at promoting R&D, tests and evaluation, and standardization, and providing users with design data (Figure 3).

4. Promoting International Cooperation

Japan is counted as an advanced nation in terms of development and application of fine ceramics together with the United States and West Germany, and with regard to themes for technical development through international cooperation, it is also making efforts to cooperate.

(1) VAMAS (Versailles Project on Advanced Materials and Standards) Project

The VAMAS is one of 18 international cooperation projects taken up by the "Working Subcommittee for Science and Technology, Growth and Employment" set up at the Versailles summit held in June 1982. Its activities were formally initiated at the Williamsburg summit held in May 1983.

The VAMAS project is aimed at promoting applications of advanced materials by R&D cooperation between participating nations for establishing a technical base necessary for use in setting 12 items of advanced materials such as engineering ceramics, polymeric composite materials, and superconductive/extremely low-temperature materials. The project is conducted by the EC and nine nations--the United Kingdom, the United States, Canada, France, West Germany, Italy, the Netherlands, Sweden, and Japan, whose respective leaders signed a memorandum of understanding.

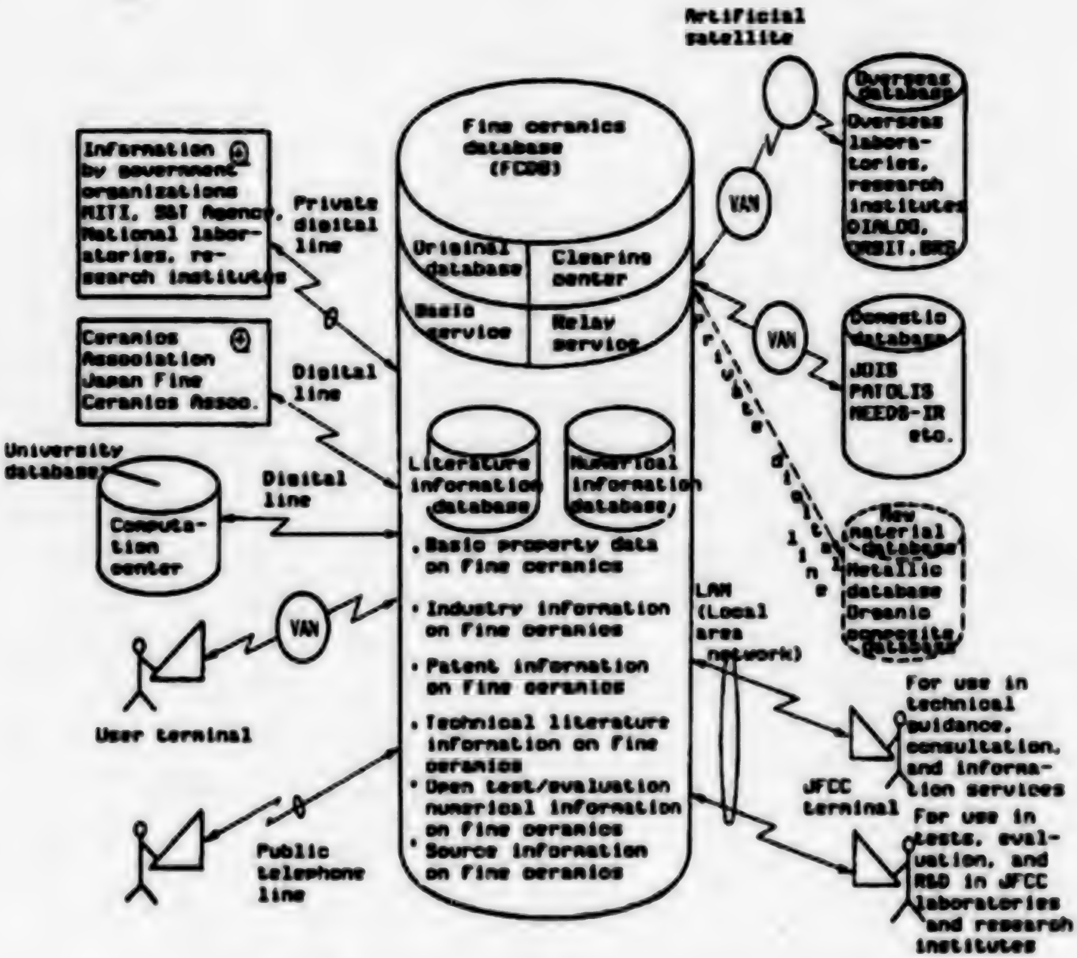


Figure 3. Planning of Fine Ceramics Database

Of the 12 items, those related to fine ceramics under R&D are, as shown in Table 3, "engineering ceramics" and "wear test evaluation technologies," with each nation initiating round robin tests--a test method to clarify problems on standardization of test methods and test machines by unifying test conditions with the use of the same specimen.

With regard to "engineering ceramics," the following round robin tests are being conducted in each participating nation: those on time dependency in four-point bending strength tests of alumina test pieces (2,000 pieces simultaneously manufactured in France) for the research on time dependency and reliability of their strength, and those on the measurement of three type of hardness--Rockwell, Vickers and Knoop--of two types of alumina with different densities and impressions for the research on measuring their physical characteristics in relation to hardness, etc.

With regard to "wear test evaluation technologies," round robin tests using different weight sand vibration speeds are being conducted on alumina test pieces in each participating nation.

Table 3. Fine Ceramics-Related VAMAS Project

Technical working subcommittee	Participating nations	Japanese committee	Organizations in charge	Research content
Engineering ceramics	France (organizer), U.S., U.K., Japan, EC	Hiroshi Okuda, managing director Fine Ceramics Center	National Research Laboratory of Metrology and Government Industrial Research Institute, Nagoya, AIST, MITI National Institute for Research in Inorganic Materials Fine Ceramics Center	The research is targeted at hardness and bending strength, basic mechanical characteristics, aimed at establishing a test method by making clear the influence of microdefects, load velocity, and environment on these characteristics. It is also aimed at clarifying the correlation between basic characteristics such as hardness and applied characteristics such as wear resistance. At present, alumina is used as a test material with silicon carbide and silicon nitride also planned for use.
Wear test evaluation technology	West Germany, (organizer), Canada, France, Italy, Japan, U.K., U.S., EC	Kenichi Matsuno, director, Material Engineering Department, Mechanical Engineering Laboratory, AIST, MITI	Mechanical Engineering Laboratory and Government Industrial Research Institute, Osaka, AIST, MITI	The research is aimed at contributing to the standardization of wear test methods by clarifying surface coating materials and wear mechanisms of ceramics: 1. Nonequilibrium reaction in sliding process--reaction between ceramics and oil agents and nondestructive analysis and evaluation of the surface layer. 2. Establishing a wear test method for new materials such as ceramics.

(2) Japan-West German Cooperation for Ceramics Research

The Government Industrial Research Institute, Kyushu, AIST, and German Aerospace Laboratory (DFVLR), Research and Technology Ministry, Western Germany, have worked on a 4-year program (budget for FY 1987, ¥10.036 million) since FY 1986 to "develop heat resistant carbon-ceramics composite materials and study their high temperature characteristics" through international specific collaboration projects--projects that further R&D by sharing research themes between laboratories and research institutes of the AIST and overseas research organizations.

The research contents include manufacturing by atmospheric pressure sintering of carbon-SiC-B_4C composite materials expected for their oxidation resistance, clarifying their basic thermal characteristics by measuring their thermal constants, and measuring and analyzing their high temperature characteristics such as thermal fatigue.

(3) Japan Trust

The "Japan Trust Project for International Research Cooperation" has been promoted by the Basic Technologies Research and Promotion Center which is aimed at promoting creative technical development by inviting researchers from overseas since 1987 and using voluntary funds from private sources. Such research exchange with Japanese research organizations include, for example inviting Dr Nancy J. Tighe from the United States for 4 months from March 1987 with the Fine Ceramics Center as her sponsor.

The Fine Ceramics Center has so far conducted international activities such as holding international symposiums and accepting visiting researchers from Canada, and it is expected that the invitation of Dr Tighe will further promote research exchange. MITI, too, plans to increase such international exchange of fine ceramic researchers through these activities.

III. Promoting Technical Development

1. R&D of Next-Generation Industrial Basic Technologies

The objectives of the R&D are to establish basic technologies to utilize ceramics as industrial structural materials. In detail, it includes the development of: 1) high-strength ceramics for application to high-temperature heat engines, etc.; 2) highly corrosion-resistant ceramics for application in high-temperature corrosive atmospheres; and 3) high-precision wear-resistant ceramics for application as fast high-temperature sliding parts. Consequently, R&D is for establishing a controlled manufacturing process for material synthesizing, for forming and sintering technologies, and, parallel to this, for developing design and evaluation technologies suited for ceramics, a brittle material.

According to the plan, research length is divided into three periods; the development of materials to meet individual characteristics and their manufacturing processes will be made with test pieces for the first period (FY 1981-1983) and with model parts of simple shapes for the second period

(FY 1984-1987). For the third period (FY 1988-1990), the establishment of comprehensive technologies for model parts with shapes close to those of practical ones to meet desired characteristics under conditions close to their practical use. In detail, this plan is to be conducted on the development of turbine parts for coal gasification combined cycle power plants and the formation of the program is presently underway.

R&D has been executed by six national laboratories and research institutes --the Government Industrial research Institute of Nagoya, Osaka, and Kyushu; the Mechanical Engineering Laboratory and Chemical Engineering Laboratory of the AIST; the National Institute for Research in Inorganic Materials, Science and Technology Agency; and the Fine Ceramics Engineering Research Association (consisting of 15 private firms)--resulting in the world's highest level of materials and sintered compacts.

2. Ultrafrontier Machining System

R&D on the ultrafrontier machining system has been underway since 1986 in the large industrial engineering research and development system (large project) of the AIST. R&D is aimed at establishing precision machining technologies with ultraprecision machining equipment to materialize machining and treatment technologies and nanotechnology needed for state-of-the-art industries of energy, precision machines, electronics, and aerospace that use excimer lasers and ion beams. System development will be done by combining the following key technologies--large output excimer laser technology, high-density ion beam technology, ultraprecision machining technology, and instrumentation/evaluation technologies. R&D is expected to last 8 years starting in FY 1986 with a total cost of about ¥15 billion.

The system is raising expectations for applications to thin film formation surface layer reforming, hyperfine machining, and separate refining of matters for materials, while with regard to R&D related to fine ceramics, research into diamond coating technology using the laser CVD method, etc. has bee initiated. As to other applications, expectations are placed on surface layer reforming (curing or softening) by injecting ions into ceramic materials.

3. Fine Ceramics-Related Research in Laboratories and Research Institutes of the AIST

The AIST has conducted specified research on high-strength ceramics under the next-generation system--large-scale research projects specifically selected to be promoted, including those commissioned to the private sector. On the other hand, the AIST's 16 laboratories and research institutes conducted 219 special research projects in FY 1986--important research, though smaller in scale than those specified, not including those commissioned to the private sector. Of those, 21 projects were implemented in FY 1987 (Table 7).

Table 7. Fine Ceramics-Related Special Research in AIST Laboratories and Research Institutes (Unit: thousands of yen)

Research theme	Research length (FY)	Laboratory and institute	FY 86 budget	FY 87 budget
Research on evaluation technology for dynamic properties of high-elasticity heat resistant materials	1985-89	National Research Laboratory of Metrology	17,339	22,244
Research on solid phase junction methods for new	1985-89	Mechanical Engineering Laboratory	15,200	18,800
Research on solidified reforming of diamond, etc., using ultrahigh-density energy	1985-89	Chemical Engineering Laboratory	18,765	15,634
Research on halogenide glass	1986-89	Government Industrial Research Laboratory, Osaka	11,300	11,000
Research on highly conductive graphite load materials	1986-88	Government Industrial Research Laboratory, Osaka	10,300	10,000
Research on ion conductive noncrystal inorganic materials	1985-88	Government Industrial Research Laboratory, Osaka	11,800	12,000
Research on technology for forming corrosion resistant films by plasma CVD	1984-87	Government Industrial Research Laboratory, Osaka	10,300	9,000
Research on development of high-performance chemical sensors	1984-88	Government Industrial Research Laboratory, Osaka	13,800	13,500
Research on high-toughness fiber composite ceramics	1986-90	Government Industrial Research Institute, Nagoya	8,900	8,915
Research on high-performance oxide composite sintered materials	1984-88	Government Industrial Research Institute, Nagoya	8,800	8,085
Research on applying ceramics to metal surface by ion beams	1985-88	Government Industrial Research Institute, Nagoya	9,795	10,034

[continued]

[Continuation of Table 7]

Research theme	Research length (FY)	Laboratory and institute	FY 86 budget	FY 87 budget
Research on functional porous ceramics	1985-89	Government Industrial Research Institute, Nagoya	9,000	9,121
Research on development of photosensitive ceramic materials	1987-91	Government Industrial Research Institute, Nagoya	--	10,003
Research on material synthesis by reaction process control	1986-91	Electrotechnical Laboratory	15,621	20,196
Research on creating new surface layer materials by active particles	1986-91	Electrotechnical Laboratory	22,330	28,480
Research on manufacturing carbon materials with vapor phase heat decomposition method	1986-90	National Research Institute for Pollution and Resources	14,578	13,580
Research on development and application of high-functional inorganic fibers and noncrystal materials	1987-90	Government Industrial Development Laboratory, Hokkaido	--	5,148
Research on development of high-performance engineering carbon materials	1985-88	Government Industrial Research Institute, Kyushu	10,000	11,680
Research on manufacturing porous chaff ceramics	1987-90	Government Industrial Research Institute, Kyushu	--	9,377
Research on development of high-temperature plastic boride ceramics	1987-90	Government Industrial Research Institute, Kyushu	--	8,985
Research on development of composite materials by intercalation	1987-91	Government Industrial Research Institute, Tohoku	--	4,957
Themes completed in previous year (four)			36,160	
Total			243,988	260,739

4. Government/Private Sector Common Collaboration

The Government/Private Sector Common Collaboration System was established in FY 1985 in the AIST. Until then, collaboration systems only allowed so-called shared research to be conducted without any exchange of researchers or joint use because of the absence of a request for a budget. In this context, the system is aimed at utilizing to the utmost the basic potential accumulated in the AIST's laboratories and research institutes and thereby implementing collaboration in the form of physical linkage in terms of personnel and funds from the private sector and between the government and private sector with the following measures:

(1) Common usage of research facilities donated by the private sector and facilities of industrial research institutes.

(2) Joint ownership of industrial copyrights of the results of the joint research between the government and private sector.

The research themes to be studied under this system are related to basic research necessary for establishing the industrial base and are regarded as the most beneficial to the public among themes that highly require collaboration between private enterprises and the AIST's laboratories and research institutes. Currently eight themes are being studied under this system, two of which are related to fine ceramics (Table 8).

Table 8. Fine Ceramics-Related Government-Private Sector Collaboration Themes

Theme/ research length (FY)	AIST laboratory and research institute	Collaborator	Research description
Research on development of highly functional materials and their biocompatibility evaluation/ 1986-90	Mechanical Engineering Laboratory Government Industrial Research Institute, Nagoya Research Institute for Polymers and Textiles	Mitsubishi Mining & Cement Co., Ltd. NGK Spark Plug Co., Ltd. Kyoto Ceramics Co., Ltd.	(1) Research on biomaterials and bioequipment Obtaining a guideline for performance evaluation of various bioceramics and new biomaterial design. A study of a ceramics material compounding method for improved mechanical characteristics of ceramics superior in their biocompatibility. (2) Research on property evaluation Evaluation of wear resistance of various ceramics. (3) Research on evaluation by a cell tissue culture method

[continued]

[Continuation of Table 8]

Theme/ research length (FY)	AIST laboratory and research institute	Collaborator	Research description
			Selection of cell species suited for biocompatibility evaluation for studying a culture method for them. Evaluation of biocompatibility of various bioceramics. (4) Research on evaluation using animal experiments Conducting various bioceramics in-bone subcuticular tests.
Research on ultraplasticity of fine ceramics and their ultraplasticity machining/ 1986-89	Government Industrial Research Institute, Nagoya	Suzuki Motor Co., Ltd. Riken Corp. (Narumi Seito) Co., Ltd. (Nihon Kagaku Togyo) Co., Ltd.	(1) Study on microstructures facilitating manifestation of ultraplasticity in fine crystal-grain zirconia ceramics made of hyperfine-grain material powder of high purity. (2) Technical development on machining devices, die materials, forming methods and working knowledge (knowhow) under high temperatures of over 1,400°C for establishing forming technology using ultraplasticity machining for fine ceramics whose ultraplasticity phenomena has been confirmed. (3) Test-manufacturing with ultraplasticity machining of ceramic automobile parts showing remarkable improvements through mass production and demonstrating the practicality of the forming process.

IV. Conclusion

As stated so far, MITI has been evolving various policies in order to contribute to the readjustment and technical development of the industrial base, while making efforts on expanding and strengthening the Fine Ceramics Center, Japan Fine Ceramics Association, and new diamond forums for readjusting the industrial base and providing assistance (various R&D subsidies) to technical development in private enterprises.

The material being watched most closely both at home and abroad is a high-temperature superconductive ceramics material. The repercussion will be extremely great when the material is put to practical use, and if superconductivity at room temperature should come true, a great industrial revolution could take place. In fact, the confirmation of superconductivity in room temperature has been actually reported from many fields. The Fine Ceramics Office is scheduled to initiate its policies, including forming a system for the comprehensive promotion of basic research to the development of applied technologies in the future while paying attention to the progress in R&D at home and abroad and making efforts to further various R&D in order to contribute to the promotion of the fine ceramics industry.

20117/9365

Revolutionary Energy Technology for Industrial Application

43062535 Tokyo ENERUGI FORAMU in Japanese Nov 87 pp 92-96

[Excerpt] 1. **"Crude Oil Recovery Technology" Which Overthrows the Theory of Petroleum Depletion in 35 Years**

The petroleum industry, although its share of energy consumption is 60 percent, seems to be in low spirits, in part because it suffers from the prevailing theory of "limited resources" which has created a strong image of a declining industry.

Since the birth of man, or more precisely since the Industrial Revolution, petroleum consumption amounts to about 460 billion barrels. The current annual petroleum consumption is about 20 billion barrels, but it is estimated that 2 trillion barrels of petroleum are still buried in the earth. However, this figure is for "the ultimate recoverable reserves" and is in the nature of a theoretical figure. More specifically, it is estimated that only one-third of the ultimate recoverable reserves or 700 billion barrels may be drilled. Therefore, if we keep up with the annual consumption of 20 billion barrels, the currently recognized recoverable petroleum resources will be depleted within 35 years according to a simple arithmetic calculation. This means that all the petroleum companies will disappear from the world in 2020 when this year's new employees come to retirement age in 35 years. On the other hand, at about the same time, the nuclear power industry expects to see the practical use of the fast breeder reactor (FBR) which is the atomic furnace dreamed of by the nuclear industry. This illustrates the sharp contrast between the dark side and the bright side of the energy industry.

The petroleum industry is placing its hopes on the development of crude oil recovery technology. Since the petroleum buried underground is subject to great pressure from the surrounding water or gases, the petroleum will naturally gush when a well is drilled. However, the continuous extraction of petroleum gradually reduces the pressure in the oil layer, so the quantities of petroleum which can be recovered under natural pressure is considered to be 20 to 30 percent of the petroleum existing in the oil layer. This level of recovery is called "primary recovery." Currently, the petroleum industry is trying to introduce the water flooding method or the gas injection method in an effort to attain a recovery rate of 30 to 50 percent which exceeds the primary recovery rate. Furthermore, the

petroleum industry has partially introduced "the secondary recovery method" or the "tertiary recovery method" based on the fire flooding method.

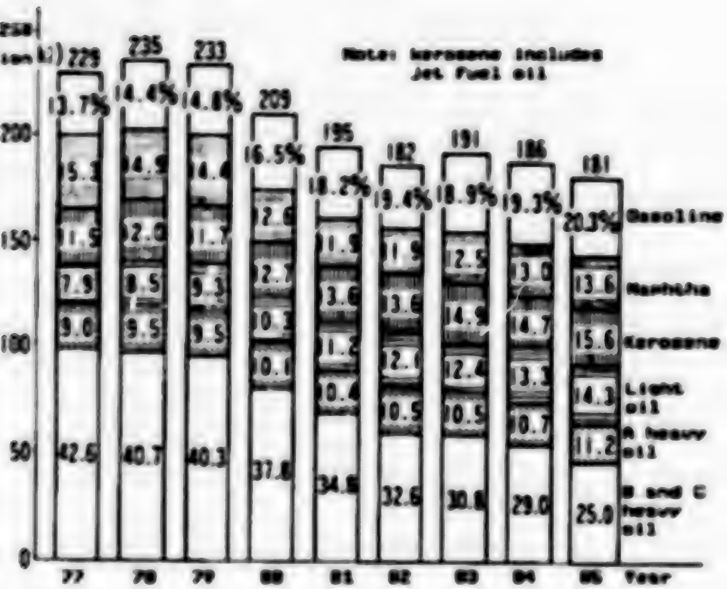
However, even these new technologies can recover only 50 percent of the buried petroleum. Therefore, the petroleum industry places great expectations to recover the last drop of petroleum on the development of a new technology called "enhanced oil recovery" (EOR).

In Japan, the "Crude Oil Secondary and Tertiary Recovery Technology Research Association" is engaged in the problem of this EOR technology. The Association was established in 1982, with 11 companies comprising petroleum developers, refiners, and plant manufacturers registered as members. The Association has invested a little less than ¥6 billion since its establishment and it is currently engaged in field tests. Although this year is tentatively considered the target year, the Association is expected to continue field testing during and after next year.

The development of the new technology targeted by the Association comprises the Micellar polymer method and the heat flooding method. The former method is being repeatedly tested in the field tests in the Sarukawa oil field in Akita Prefecture and the Niitsu oil field in Niigata Prefecture. This method enhances the crude oil recovery rate by injecting an interface activator into the oil layer to reduce the boundary tension which is backed by the injection of a polymer aqueous solution. This method is considered most effective in its application to the medium light oil field in particular, but the bottleneck is the high cost of the interface activator. It is similar to a detergent and is extremely costly to manufacture. With this method, the cost is $30 to $40/barrel. Therefore, this method will not be adopted so long as the current crude cost remains as high as $18/barrel.

The other method which is called "heat flooding" is designed to reduce the viscosity of crude oil by the application of heat produced by injecting high temperature steam into the oil stratum. As for this method, the research Association is developing a method to produce steam by directly installing into the oil stratum a burner or boiler which is 7 inches in diameter and about 9 meters in length. It is expected to be effective in relatively heavy oil fields. The manufacture of the boiler and burner is expected to be completed this year, and demonstration tests are scheduled in some overseas oil fields during and after the next fiscal year.

For either the Micellar method or the heat flooding method, the recovery cost is rather expensive. The view of many in the oil business is that from the middle of the 1990s the cost of crude oil will rise to $30 to $40/barrel by 2000. At this stage, greater expectation is placed on the full-fledged introduction of both technologies. It is natural that Japan, which is poor in resources but a big petroleum consumer should develop the technology which theoretically can recover 80 percent of underground petroleum to prepare for that time.



Structural Trends in Demand for Petroleum Products in Japan

If this crude oil recovery technology can actually be used, the years to mine the crude oil will be increased sharply, from the current 35 years to 80 years.

2. Unused Resources Application Technology Is a Modern Alchemy for Petroleum Industry

It is expected that total domestic demand for fuel oil in 1986 will be reduced to 107.8 million kl, which is 98.7 percent of the demand for the previous year, and is due to the decline in the domestic demand for C heavy oil centering on the electric power companies, a reaction to the increase in the demand caused by the severe winter in 1985.

On the other hand, it is expected that the total domestic demand for the fuel oil during and after 1987 will show little change up to FY 1989. Then in FY 1990 it will be reduced to 107.6 million kl, a decline of 1.9 percent compared with the previous year.

As the main factors responsible for these trends, the demand for gasoline and middle cuts such as kerosene, light oil, and A heavy oil are making steady progress; on the other hand, it is predicted that the domestic demand for C heavy oil for electric power and other services will continue to decrease under the influence of the introduction of nuclear power generation and other substitute energy forms.

Under these conditions, research is being conducted to reduce the refinery bottom yield (the target figure intended to indicate whether or not the crude oil is heavy enough for refining), and to improve the yield of the

middle products (kerosene, light oil, A heavy oil, and jet fuel), and to reduce the yield of B and C heavy oil.

On the other hand, crude oil may be classified as heavy or light crude oil. The yields of gasoline, kerosene, light oil, and A heavy oil vary greatly, depending on whether heavy crude or light crude oil is refined.

It cannot be said absolutely that the technological development of "these heavy oils" and the quality changes in the crude oil itself have contributed to enhanced refinery performance.

Currently, the petroleum environment both domestic and abroad is taking a turn favorable to the consumers permitting the consumers to obtain good quality "light crude oil" at a low price, and this prevents the technological side from coming to the fore.

However, from the standpoint of long-term policy, strenuous efforts are being made to resolve the gap between the increase in demand for middle and light oil and the decreased demand for heavy oil. The target of the "heavy oil" countermeasure is "to develop a new technology required to process a large volume of heavy oil while producing the middle cut" and includes the development of heavy oil cracking technology.

The cracking technology comprises thermal cracking, contact cracking, and hydrogen cracking. Many thermal technologies are already established and many plants are operating both in Japan and abroad. However, it is difficult to obtain kerosene and light oil by this method, although gasoline and gas can be obtained. In the case of Japan, the market for pitch and coke which are generated in large quantities is limited, and Japan may face some problems to solve in terms of the overall application. Therefore, Japan has carried out technological research and development centered on contact cracking and hydrogen cracking for middle cut increased production.

The refinery plants based on the fluid catalytic cracking process (FCC) which produces gasoline are increasingly expanding as desirable plants, and research seeks to reduce the catalyst costs for the cracking and to improve the process.

Since the off gases discharged in large quantities from the FCC plants contain useful components such as thylene, propylene, and butylene, the establishment of membrane technology which permits the transmission of only the useful components contained in the olefin gases is being planned in an effort to use "crude oil" completely.

In addition, research is underway to develop low temperature waste heat recovery equipment which is used most effectively to recover unused low temperature waste heat below 200°C, and to heat the unused waste heat for process heating, and to develop an effective waste heat application system technology.

As described above, the petroleum technology which uses unused resources effectively during many steps beginning with crude oil and ending with refined products is capable of using even the dregs of crude oil. A certain researcher added: "More and more new technologies will be created in the future."

3. Are Huge Natural Gas Deposits Found Even in Japan?

"Fossil fuels such as petroleum, coal, and natural gas are the remains of ancient living creatures (plants or microorganisms) which have changed through long ages and hence their reserves are limited (organic theory)." However, a new theory which shakes up this "common sense" is quietly and steadily penetrating to many concerned people, arousing high expectation.

This new theory, called the "inorganic theory," holds that most fossil fuels are the hydrogen or methane which existed when the earth was formed, were covered by the earth's crust and since then have gradually been exuded. According to this inorganic theory, an extraordinary amount of reserve of petroleum and natural gases are buried underground.

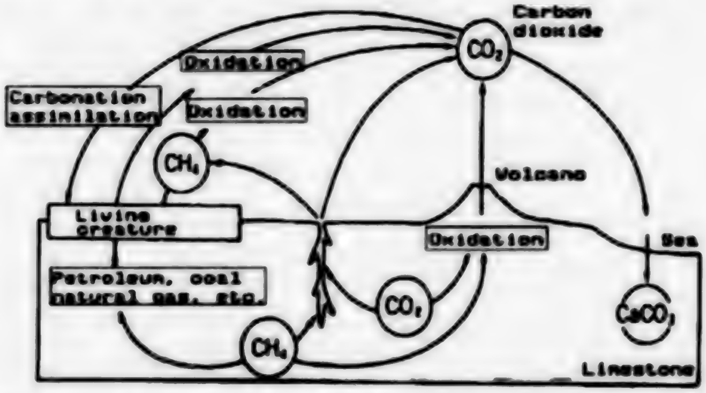
The main proponent of this new theory is Professor Thomas Gold of Cambridge University, United Kingdom, (formerly a professor of Cornell University), who has advocated this theory for the past decade, and steadily increased his sympathizers. Professor Gold is a celebrated cosmologist. Therefore, his extensive knowledge about the construction of the universe, including the earth, is applied to the background of this theory. The inorganic theory of petroleum originated in the 19th century. Recently, it was highlighted and became suddenly realistic in proportion to the advances in resources prospecting based on man-made satellites or drilling technology.

Especially the presence of huge amounts of hydrocarbon gases in Jupiter and Saturn has been recently confirmed while the presence of methane gases is also confirmed even in Uranus and Pluto. This fact strongly implies the possibility that the earth which belongs to the same solar systems conceals huge amounts of inorganic gases as well. These gases are called "earth deep layer gas" and are thought to be generated from volcanic eruptions, earthquakes, and the strata in the submarine ocean plates.

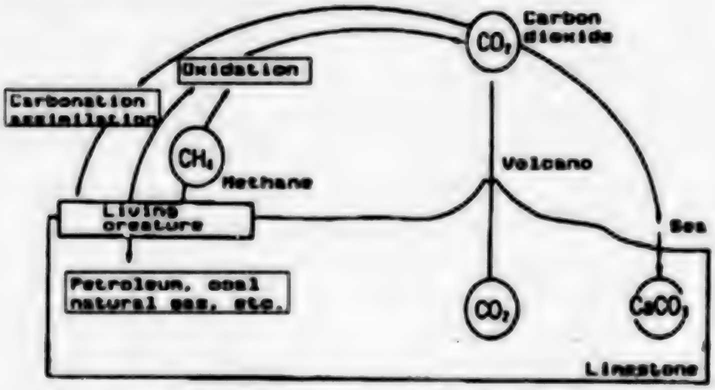
The gases freed from the accumulated layers of hydrocarbon (mostly methane) in the earth rise slowly through the voids in the crust of the earth to areas of weak pressure, combine with each other, and rise. The gases are forced to stop their upward movement when they reach an ultradense cap-shaped rock formation, thereby forming a gas reservoir layer.

Generally, the gases rise through brittle portions in the rock formation or they are discharged to the surface when the rock formations fracture during earthquakes. However, huge amounts of gases are considered still to be stored in the depths of the earth.

The generation, transfer, and changes of methane gas according to the theory advocated by Professor Gold



The generation, transfer, and changes of methane gas according to the traditional theory



Source: "A Conversation With Thomas Gold" (GRI DIGEST 1981)

4. Concrete Development Prospect Urged

In Sweden, the state-owned power company VattenFall is carrying out a full-fledged test boring at the gigantic meteorite crater Siljan Ring (a ring-shaped region) at a point 300 km northwest of Stockholm.

Sweden is not blessed with natural resources except for hydroelectric power. Furthermore, the country is proceeding with its independent policy to abolish before 2010 all the atomic power plants which now provide 50 percent of the total power generating capacity. Therefore, Sweden is forced to assume new energy resources no matter what form they might take. Therefore, the country gives specific attention to the development of the deep layer gases in the earth.

In this area, 360 million years ago, a gigantic meteorite fell and produced a huge crack which reached a depth of 64 km from the surface. At the same time a huge crater, 60 km in diameter and 3 to 6 km deep, was produced. The cracks reached the mantle which is the source for generating the earth's deep layer gases. The impact and the vertical movement of the rock

layer produced many voids in the porous underground rock strata which absorb gases easily.

The upper rock formations were melted with a very high temperature during the collision which produced the dense rocks which confine the gases within the rocks, not allowing them to leak out. Therefore, the best conditions to verify the earth's deep layer gases are provided. In addition, the diffusion of natural gases over the ground surfaces are reportedly observed in the area. Professor Gold is watching developments with confidence in his theory. The test boring is completed to the depth of 6,400 m. Even in Japan interested parties show a growing tendency to carry out boring for scientific research. Since Japan is an earthquake archipelago, Professor Gold's new theory cannot be neglected.

5. Superconductivity Causes a Revolution in the Electric Power Field

The Moonlight Project Promotion Office of the Science and Technology Agency reported that the generator manufactured by applying superconductivity technology has reduced its axial length by 40 percent and its weight by 50 percent based on the results of the feasibility investigation conducted over the past 3 years, thereby achieving a reduction in both size and weight by a large margin compared to conventional generators.

This means a breakthrough in the manufacturing limits of the conventional generator. Further, it contributes greatly to the stabilization of the power system, increases the transmission capacity by 50 percent, and upgrades generator efficiency by 0.5 to 0.7 percent.

The economic efficiency of this superconductivity-based generator will have advantages over the standard generators now operating when its capacity exceeds 300,000 kw. The generator will increase its superiority to the extent its size is increased. It is reported that the annual cost savings will amount to about ¥700 million for the 1 million kw class.

The superconductivity-based poser storage system is considered promising as a new power system in the future. According to plan, for the power must be stored as magnetic energy, an ultra large-sized superconductive coil is needed. For this reason it must be built on a rock foundation to support a strong magnetic force, thereby reducing the construction cost.

However, if practical wire rods which are made of oxide-based high temperature materials are developed, a new system configuration will be possible at the temperature of liquid nitrogen. Therefore, it is predicted that the enhanced durability of the rotor based on the simplified insulation construction and the improved efficiency of the refrigerating system will reduce the manufacturing cost.

Furthermore, superconductivity magnets for nuclear fusion are capable of creating a stronger magnetic field in a large space with less power consumption. In addition, they are capable of increasing the high current density (more than 20 times higher than conventional magnets) of magnets

for elementary particle accelerators and magnetic flotation trains so that they can be more compact due to reductions in size and weight.

MITI's Science and Technology Agency plans to develop an energy system based on the application of superconductivity. Especially, the Agency is scheduled to start "Superconductivity Power Application Technology" as energy reduction technology research development (as part of the Moonlight Project: ¥1.67 billion requested in the outline budget for FY 1988) starting next fiscal year.

This development project calls, over a period of 8 years, for the technological development of superconductivity wiring rods which include oxide materials and the collection of reliability data based on the manufacture of model equipment of the 70,000 kw class and the collection of basic engineering data about large-size equipment. It is planning to introduce a pilot system of the 200,000 kw class into the power system, then use it as a demonstration plant.

Our dreams about power generation, transmission, and transformer substation systems based on superconductivity in the 21st century system will continue to grow.

20136/9365

Trends in Recognition/Identification Technology Examined

Measurements, Identification Using Laser Beam

43064017a Tokyo SENSA GIJUTSU in Japanese Nov 87 pp 18-21

[Article to Hiro Yoneu, Toyohasi University of Technology: "Trends of Measurement and Identification Technology Using Laser Light"]

[Text] Thanks to its outstanding features not available with ordinary light, laser light has been used in various measuring and identification applications. Measurement by laser has a relatively long history and gas laser was used first. Since the start of mass production of semiconductor lasers in recent years, the scope of laser applications has rapidly expanded to include the field of recognition. All this is due to the outstanding features of semiconductor lasers; namely, lightweight and small size, high reliability and easy operation, as well as improved performance. Research and development are also being aggressively promoted on lasers featuring short wavelength waves and high output, and the results have widened the scope of their applications.

The following describes technical trends in the fields of measurement, identification and recognition, and semiconductor lasers.

1. Measurement

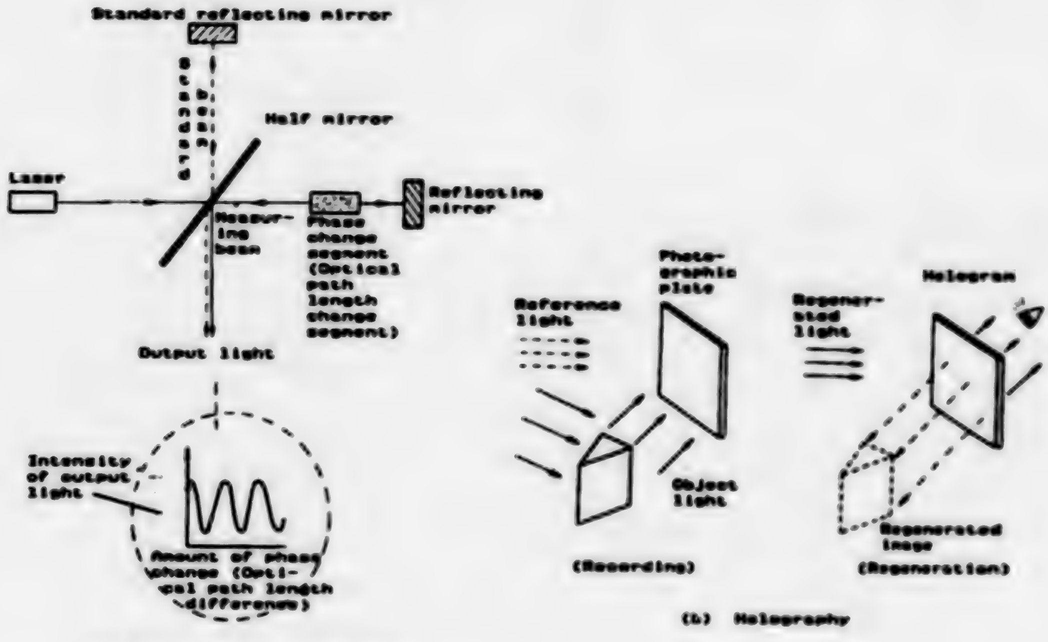
The following features of laser light are used in measurement:

(1) Monochromatic frequency → interference, diffraction

(2) Polarization → Kerr effect, Faraday effect

(3) Spatial coherency → directivity, convergence

Since the interference described in (1) is the effect arising from the overlapping of light waves, it boasts a high measurement accuracy equivalent to a fraction of the wavelength. A widely used operating principle is the principle of Michelson's interferometer. In Figure 1(a), because of the difference in the lengths of the two laser beams generated as a result of the light splitting, there arises a phase difference between the two beams, causing them to interfere with each other at their point of



(a) Michelson interferometer

(b) Holography

Figure 1.

convergence. In other words, intensities of the output light vary in accordance with the phase differences. Measuring the change in the intensity of the light enables us to know the phase difference, that is, the difference in the lengths of the optical paths.

In Figure 1(a), when the reflecting mirror is an object to be measured and the phase change segment is the distance of space, the device is a displacement gauge. Depending on the content of the phase change segment, various types of sensors can be manufactured.

When the phase change segment contains a substance whose refractive index and length vary with the temperature, the result is a temperature sensor, and when the phase change segment contains a material whose refractive index and length vary with the pressure, the result is a pressure sensor.

Included in the interference effect described in (1) is holography, generated as a result of an interference between the object light and the reference light, which is shown in Figure 1(b). When laser light is shone at a three-dimensional object, amplitudes of the light from the object's surfaces and the light's phases are recorded in the interference patterns. Consequently, the shape of the three-dimensional object and the contrast of light and dark on the object can be obtained from the interference patterns. Holography, therefore, is used for measurement of the shape and distortion of optical parts like mirrors and lenses, and precision machined parts. The technology is also used to measure stress distortions and thermal distortions as well as in various testing equipment.

The polarization mentioned in (2) is generally most conspicuous in semiconductor lasers. Since the plane of polarization rotates in response to a magnetic field, the strength and direction of the magnetic field can be learned by measuring changes in the light's strength using a photo detector.

The good directivity described in (3) makes it possible to propagate through space for a long distance. A measurement of the time from the moment when a laser beam is emitted at an object until the moment when the beam is bounded off the object to come back to the laser enables a high precision measurement of the distance between the laser and object. The technique can be used in various applications, such as in the digging of tunnels or in the measurement of topographical distortions.

2. Identification and Recognition

In the field of optical data processing, the process of identifying the existence or nonexistence of a pattern is widely used. Typical examples are compact disks, video disks, and optical disk memories. Only laser light can identify pits 0.5 μ in width and 0.11 μ in depth. Here, the convergence described in (3) and the interference described in (1) are used. As shown in Figure 2, a semiconductor laser beam of 0.78 μ in wavelength is focused to a beam of about 1.5 μ in diameter on the optical disk. When the light hits a pit, the beam bounced off the pit and the beam reflected from the pit's outer edge interfere with one another, weakening their intensity.

Where there is no pit on the disk, there is no interference of light, so it is bounced off the disk, losing none of its strength. Consequently, a measurement of the intensity of returning light makes it possible to tell whether there is a pit or not. The shorter the wavelength, the smaller the diameter of the focused laser beam, hence the higher the recording density.

In the erase/write type of optical disks and memories, the Kerr effect described in (2) is used in place of interference mentioned in (1). This is because pits are not physical irregularities but are differences in the direction of magnetization of a magnetic thin film.

The bar-code reader is also a typical example of identification by laser light. An He-Ne gas laser with a wavelength of 0.63 μ reads a bar code. Reflectivities of the black inks are not standardized, so reflectivities from the black portions differ greatly in the near-infrared region. Therefore, visible radiation lasers are exclusively being used.

Recognition of data, voice, and image is the world of data processing where computer technology is made the most of. Here too, basic research is being promoted on optical computing and optoelectronic computing. The parallel computation that takes advantage of parallelism of light is the basis. That is, the optical computing technology is by far the faster in processing speed than the conventional computer technology. Figure 3 is an example of a new computation and memory method provided with a feedback

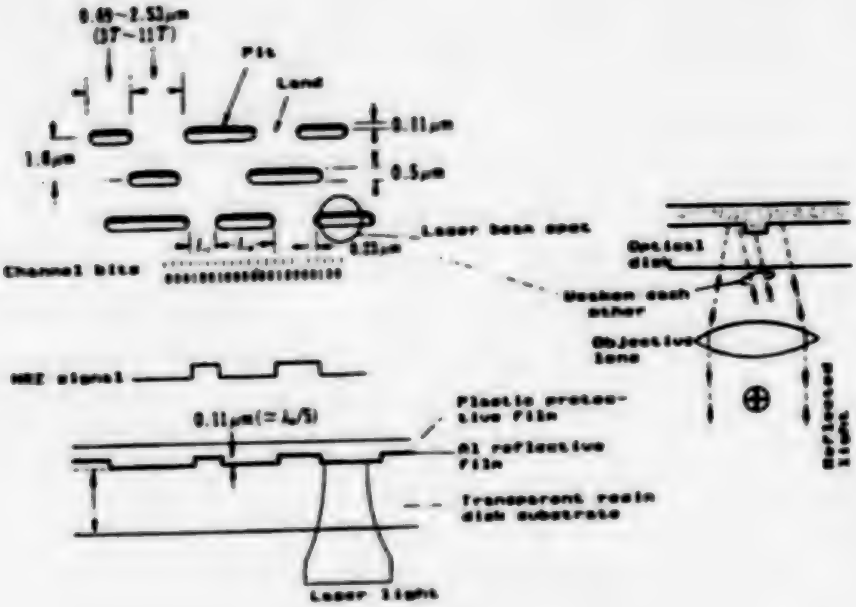


Figure 2.

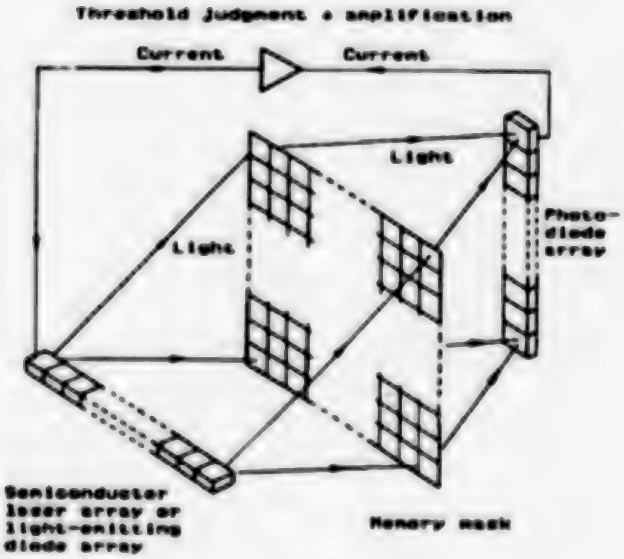


Figure 3.

mechanism. The black and white matrices (memory masks) function as memories. In this case, inputting of an 8-bit partial data enabled retrieval of a 20-bit complete data. This is a sort of association memory. The objective is to extract complete data from the hint of incomplete data.

It may be feasible in the future to recall complete data from incomplete voice data or image data.

3. Semiconductor Lasers

The shorter the wavelength of laser light, the smaller the spot into which it can be focused, and the higher the sensitivity of a recording medium or a detector. In view of their uses, small and lightweight sensors are desirable. To that end, the development of shorter wavelength semiconductor lasers is much awaited. At present, AlGaAs lasers with a wavelength of 0.78 μ are produced at a rate of about 1 million units per month for CDs. Semiconductor lasers of shorter wavelengths have yet to be commercially manufactured on a full-scale basis.

A short wavelength semiconductor laser with bright prospects for practical use is the AlGaInP laser. In an $(Al_xGa_1\text{-}x)0.5In_{0.5}As$ crystal, when the composition ratio of Al, x, is increased, the transmitting wavelength becomes shorter, in principle it is capable of going below 0.60 μ. In a laser using the $Ga_{0.5}In_{0.5}As$ active layer of x=0, a continuous oscillation has been achieved in the 0.65-0.68 μ wavelength range at room temperature. Again, using an $(Al_{0.2}Ga_{0.8})_{0.5}As$ active layer of x=0.2, a continuous oscillation at a wavelength of 0.62 μ has been recorded at 3°C. In other words, lasers with a shorter wavelength than that of the He-Ne gas laser, which is 0.63 μ, have been realized. It will not be too long before red semiconductor lasers with a wavelength in the 0.6 μ band are put to practical use.

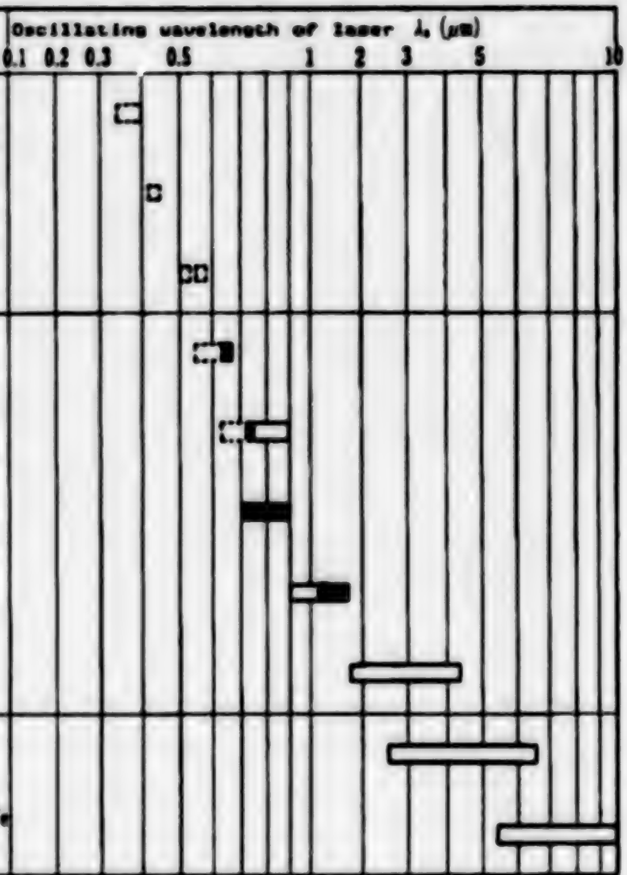
As for green and blue lasers with shorter wavelengths than the red lasers, Ar gas lasers are the mainstay at present. For fabricating semiconductor lasers, the II-VI groups of compound semiconductors, such as CdSeS for green, and ZnSeS for blue, or the I-III-VI groups of compound semiconductors, such as $CuZlGa(SSe)_2$, are needed. To achieve these semiconductor lasers, research needs to be promoted in such basic fields as the epitaxial technology for obtaining good quality crystals and the material properties control technology.

In the field of ultraviolet rays, excimer lasers are the mainstay. As for small-size ultraviolet lasers, the method of generating a second harmonic by combining a semiconductor laser with a wavelength below 0.78 μ with a nonlinear optical crystal like $LiNbO_3$, is considered promising.

In the near to middle infrared region of spectrum with wavelengths of from several microns to several tens of microns, light is much absorbed by particles of atmospheric pollution gases and particles of reaction gases. Therefore, the distribution of gases can be detected and monitored by letting varied wavelengths of laser light pass through these gases and examining the absorption spectrum. Semiconductor lasers like the PbSnSeTe laser can be operated only at low temperatures, but as is shown in Table 1, they can cover a broad scope of wavelengths. A change in the temperature leads to a change in the wavelength of the semiconductor laser. Recently, research is being made on a method of altering the wavelength by changing current through an improvement on the semiconductor laser's structure.

Table 1.

Group	Active layer	Clad layer	Substrate crystal
II-VI	$ZnSe_{1-x}S_x$	$ZnS_{1-x}Te_x$	GaP (GaAsP)
	$ZnSe_{1-x}S_x$ $CdSe_{1-x}S_x$	$ZnS_{1-x}Te_x$	GaAs
	$ZnSe_{1-x}Te_x$	$ZnS_{1-x}Te_x$	InP
III-V	$(Al_xGa_{1-x})_{0.5}In_{0.5}P$	$(Al_yGa_{1-y})_{0.5}In_{0.5}P$	GaAs
	$In_{1-x}Ga_xAs_yP_{1-y}$	$Al_xGa_{1-x}As$	GaAs (GaAsP)
	$Al_xGa_{1-x}As$	$Al_yGa_{1-y}As$	GaAs
	$In_{1-x}Ga_xAs_yP_{1-y}$	InP	InP
	$Ga_{1-x}In_xAs_ySb_{1-y}$	$Al_{1-x}Ga_xAs_ySb_{1-y}$	GaSb
IV-VI	$Pb_{1-x}Eu_xSe_yTe_{1-y}$	$Pb_{1-y}Eu_ySe_yTe_{1-y}$	PbTe
	$Pb_{1-x}Sn_xSe_yTe_{1-y}$	$PbSe_yTe_{1-y}$	$Pb_ySn_{1-y}Te$ (PbTe)



Continuous oscillation at room temperature

Pulse oscillation or continuous oscillation at room temperature

Estimated region available for laser oscillation

Table 1 shows the wavelength scope that semiconductor lasers can directly cover. A long tie is needed for the R&D of a new semiconductor laser based n crystal growth technology and for its practical use, but the growth of sensor technology based on shorter wavelengths is considered to have great potential.

Trends in Photoelectric Proximity Sensors

43064017a Tokyo SENSA GIJUTSU in Japanese Nov 87 pp 22-24

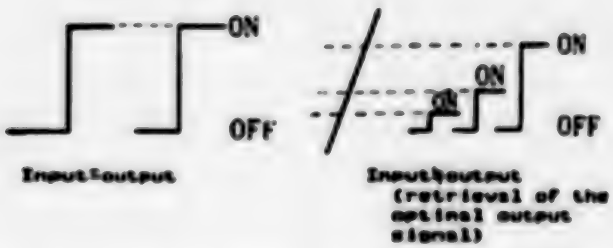
[Article by Akio Yuzuki, Marketing Office, Sensor Division, Omron Tateishi Electronics Co.: "Technical Trends in Photoelectric and Proximity Sensors"]

[Text] Of all kinds of sensors designed for "recognition and identification," photoelectric and proximity sensors are the most general-purpose type of sensors, and the market for these sensors has expanded greatly in the past 20 years. With the market growth, many new

technologies have also been developed. The field of FA, that is, factory automation, is rapidly advancing in industry, and photoelectric and proximity sensors lay the main role in sensing and transmitting the best control signals to PCs. The key to effective use of a sensor is to make the most of its performance capability. With that in view, the following briefly describes technical trends in photoelectric and proximity sensors.

1. How To Use Sensors

The author has said that the key to effective use of a sensor is to make the most of its capability, and to that end, it is necessary to recognize the "continuity" of the sensor input signal. Although the input signal is "standardized" in micro-limit switches, in photoelectric and proximity sensors the input signal is continuous and the optimal output logic signal has to be determined by the user (Figure 1). In other words, the characteristics and rated values of a sensor listed in a catalog are only "points" under a certain condition. In estimating the performance of a sensor under the plant site condition, care needs to be taken lest too large a margin is set aside in the sensor capacity, for this would fail to tap the full potential of the sensor.



(a) Uniformity of input signal (micro-limit switch)

(b) Continuity of input signal (photoelectric and proximity sensors)

Figure 1. Uniformity and Continuity of Input Signal

2. Photoelectric Sensors

(1) Self-diagnosis Function

Recent photoelectric sensors are mounted with a self-diagnosis function in the form of either a display or a signal output. This is to prevent unstable operations and spontaneous erroneous operations from occurring either when ON or OFF, which occur either as a result of the user setting aside too large a margin or as a result of the user not fully recognizing the continuity of input signal and thus adopting a sensitivity setting that is lacking in reserve. For stable operations, sensors have to be stable both at the time of ON and OFF based on the standards of operating levels.

As shown in Figure 2, when using the operating level as the standard, there are many causes for unstable operations. Some self-diagnosis systems are provided with the functions to diagnose only the smearing of lenses and

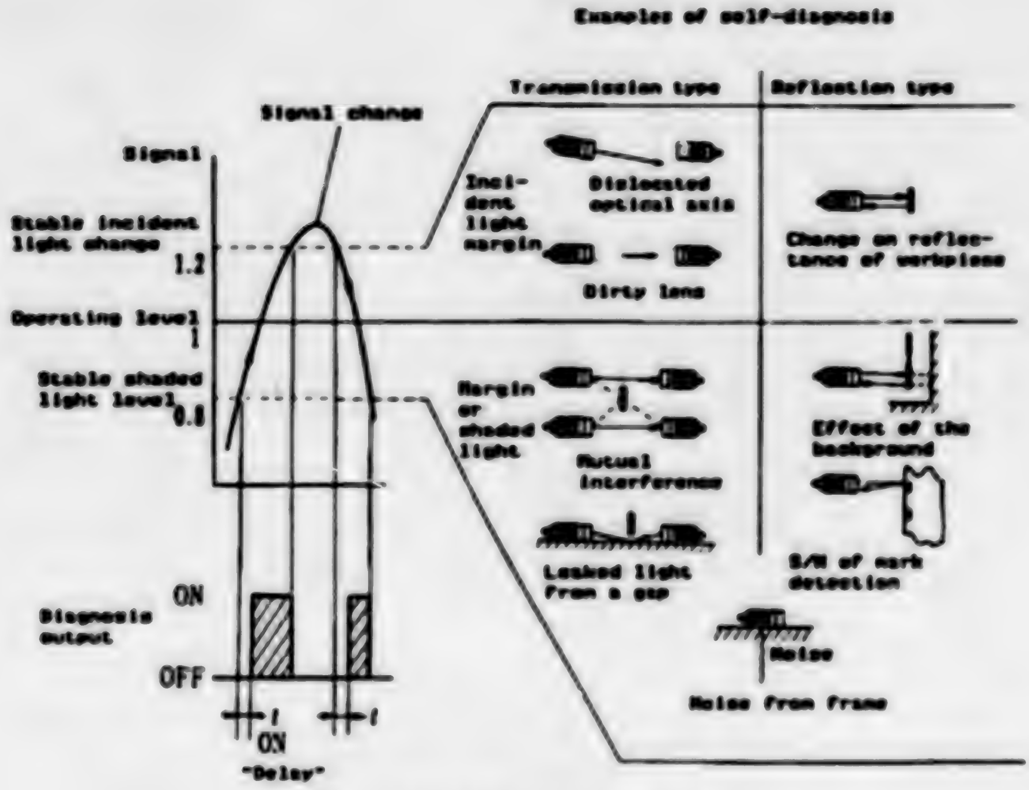


Figure 2. Self-Diagnosis Function

drift in the optical axis, but for a stable operation, systems provided with functions for diagnosing both ON and OFF ought to be used. In an air-conditioned environment where the surrounding temperature scarcely varies, the input signal undergoes little change because of temperature, so care needs to be taken lest too large a margin is set aside.

(2) Mutual Interference Prevention Function

Of photoelectric sensors, the type of sensor drawing particular attention these days is the fiber-optic sensor. Besides satisfying the qualities demanded of a sensor, light weight, thin, short, and small, fiber-optic sensors are resistant to noise and a plural number of the devices can be installed in a narrow machine space.

However, fiber-optic sensors radiate at a wide angle of 60 degrees, causing beams to interfere with each other, so too large a number of sensors cannot be installed in a small space. In such a case, if the sensors are provided with a mutual interference prevention function, they can be installed side by side in a small space, thus enabling effective control using low-cost sensors.

The mutual interference prevention function is achieved by conducting a logic operation in the pulse modulated light of a photoelectric sensor in an exclusive IC, so the technique is employed not only in fiber-optic

sensors but also in all of the main photoelectric sensors. Furthermore, since the function is conducted in an IC, there is no increase in the cost of sensors because of the function.

(3) Mirror Surface Rejection Function

Compared with the transmission type of photoelectric sensors, the regression reflection type of photoelectric sensors has advantages such as economy of wiring, for wires are arranged on one side as well as in the installation space because sensors are installed only on one side, and low costs. However, they have not found as much use in Japan as in Europe. The reason is that the regression reflection type of photoelectric sensors receive reflected light from the surface of an object to be detected, causing them to perform erroneous operations.

Recently, a regression reflection type provided with a "mirror surface rejection function" that solves this problem using a polar filter has been marketed. Consequently, a new application based on the function of the transmission type but incorporating advantages of the regression reflection type will come to find much use in the future.

(4) Auto-Register Mark Sensors

Conventional mark sensors required selection of a proper light source, either green or red in color, depending on a mark to be detected, as well as a readjustment each time there was a change in the setup, so they were not so popular with users.

Recently, mark sensors equipped with both green and red light sources that have eliminated the need for adjustment in sensitivity have been marketed.

(5) Sensors for Detection of Transparent Bottles

A regression reflection type of sensor can detect transparent bottles from end to end, thus making it possible to detect bottles stalled on a conveyor line. They can detect transparent films.

3. Proximity Sensors

Proximity sensors are based on various different principles and include the high-frequency oscillator type, capacitance type and magnetic type. But from the volume of demand, proximity sensors are almost 100 percent high-frequency oscillators. The basic difference between limit switches and proximity sensors which developed as replacements for the former is the "continuity" of characteristics. For example, when one says the detection distance is 10 mm, the conditions are that the material must be iron, that it must have a thickness of 1 mm, or that it must be more than 30 mm^2 in size. In other words, the material quality, its thickness and its area are factors that determine the detection distance. When using high-frequency oscillator type proximity sensors, how to make the most of these variants is the key to effective use. Recently, even more exclusive types of proximity sensors with special uses have been placed on the market.

(1) Proximity Switches To Counter Aluminum Chips

These sensors are free from erroneous operations even when swarf of aluminum and cast iron removed by a machine tool gets stuck on their detection heads and are able to detect correctly the workpiece.

(2) Detection of Passage of Small Metals

These sensors detect passage of small metal chips, such as a small metal chip (diameter 0.3 mm, 1 mm in length, steel wire) naturally falling from a height of 10 cm through a range of ϕ20 mm (equivalent to a speed of 1.4 m/s).

(3) Transmission Couplers

These couplers electromagnetically couple the high-frequency oscillation of a proximity sensor with a separately installed coil by mutual induction. Thanks to coupling by mutual induction, they can detect workpieces and transmit signals without the use of cords and electric power sources (Photo 1).

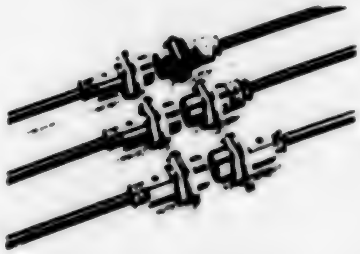


Photo 1. F92A Type Transmission Couplers

(4) Proximity Switches To Counter Sputtering

These sensors have Teflon as case material for their detection surfaces, so as to prevent erroneous operations caused by the attachment and deposition on their detection surfaces of sputter from a welding machine.

4. Sensor Controllers

The most important point in the use of photoelectric and proximity sensors is how to incorporate them in the production process for in-line inspections. In other words, the objective is not to use them as mere substitutes for limit switches in the detection of passage or positioning of an object, but to incorporate them in the production process for automation of the in-line inspection process. The objective is to speed up the flow of the line and to raise productivity by automating the conventional inspection processes, the off-line inspection in which products are randomly removed from the production line for inspection, and the on-line inspection in which products are visually inspected.

To be concrete, a single workpiece is combined with several sensors, a synchronizing sensor sets up an inspection timing, and in an instant (1 ms) an inspection sensor retrieves inspection signals. A sensor controller locally processes the plural number of signals and combines them into a single necessary signal to be transmitted to a PC. This way, savings are achieved in the wiring to the PC, the number of input points, and processing time.

This local "inspection machine," by sensor controller, can input a maximum of eight points into sensors and can process with a response speed of 1 ms. Sensor controllers are "inspection machines" indispensable for in-line inspections (Photo 2).

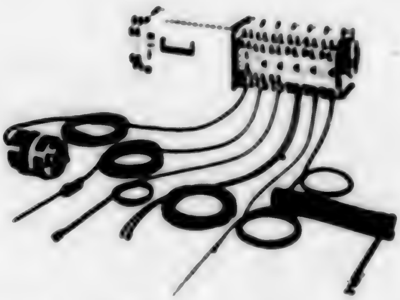


Photo 2. S3D8 Type Sensor Controller

5. Future Trends

Photoelectric and proximity sensors are expected to find increasingly specialized uses, one group of sensors going the way of downsizing, with the other group following the intelligence path through such means as linear signals. Underlying all it will be the demand for high reliability products. As for reliability, the trends are already seen in the case of proximity sensors, such as vacuum defoaming of the infused resin, laser trimming, and automated production by wire bonders and others. As for photoelectric sensors, linear signal-based general-purpose products incorporating a laser light source are expected to become the mainstream.

Trends in Application of Optical Fibers

43064017a Tokyo SENSA GIJUTSU in Japanese Nov 87 pp 25-28

[Article by Muneyoshi Sato, Acoustic Research Office in the Standard Measurement Division, Electrotechnical Laboratory: "Technical Trends in Application of Optical Fibers"]

[Text] Sensing technology using optical fiber is classified into two cases, one is when the light itself is the targeted data, and the other is when the light is used as a carrier of data. In this paper, image transmission technology using optical fiber is described as an example of

the former case and the distribution type optical fiber sensors are described as an example of the latter case.

1. Image Transmission by Optical Fiber

To transmit two-dimensional images as complete images, there is an image transmission technique using a fiber bundle, called image guide or fiberscope. Since each fiber in the bundle transmits an image point entering the input end as a ray of light independent of others, at the output end the image from the input end emerges as a complete image. Thanks to the flexibility and good environmental characteristics of optical fiber, the technique is widely used in medical and industrial fields (Figure 1).

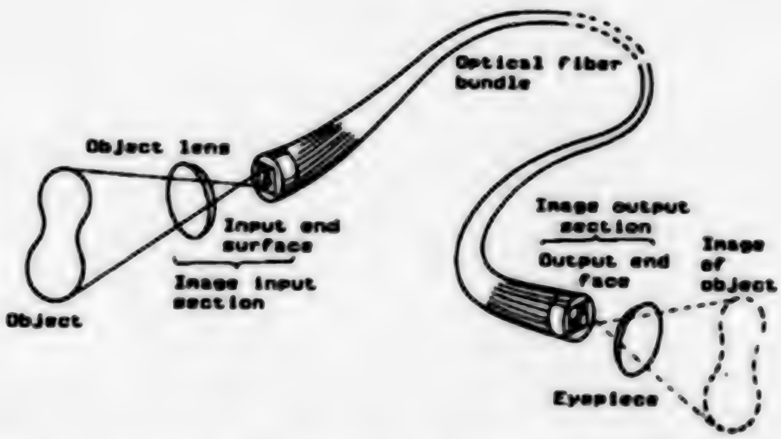


Figure 1. Direct Transmission of Image by Optical Fiber

Various technical developments have been made in various technical fields, such as the utilization of quartz fibers that will enable long-distance transmission of broad bandwidth images (from infrared to ultraviolet), the use of small-diameter fibers to enhance cable flexibility, an increase in the number of pixels to increase resolution, the technique of bundling fibers of different diameters in order to prevent moire generated when an optical fiber bundle is connected to a TV camera. Fiber bundles with excellent resistance to heat and radiation have also been developed.
Table 1 shows the performance of such a product featuring high heat resistance.

Since the fiber bundle is resistant to rigorous environments involving high temperature, low temperature, high pressure, strong electromagnetic field or radiation and because it can be snaked through a narrow place, it is used for observation of the interiors of high temperature furnaces and atomic reactors. Furthermore, since the product can send infrared images, it is also used for temperature measurements. Figure 2 shows a thermal imagery monitoring system using infrared fibers arranged in a shape of a tape.

Table 1. Example of Heat-Resistant Fiber Bundle for Image Transmission

Number of pixels	50,000
External diameter (video section)	ϕ12 mm
External diameter (transmission section)	ϕ9 mm
Field of vision	25-50 degrees
Observation distance	10 mm and up
Temperature	600°C
Allowable bending radius	150 mm
Outer sheath	SUS flexible tube

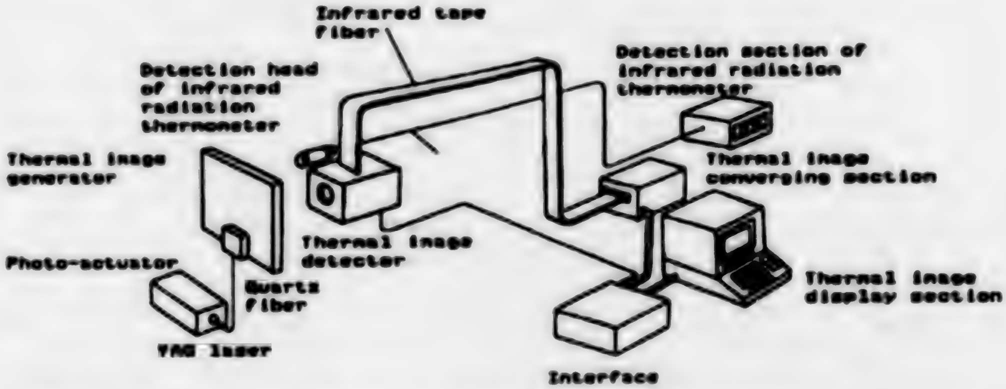


Figure 2. Thermal Imagery (Infrared Image) Monitoring System

2. Distribution Type Fiber-Optic Sensors

As described above, optical fibers have been used to directly transmit images, but the use of optical fibers as sensor elements or as transmission paths of sensor signals in fiber-optic sensors is drawing attention. Sensing technology using light has inherent features of high sensitivity, high speed, and high precision. Combining the technology with an optical fiber capable of freely transmitting light to any desired place makes it possible to take measurements by a method that is different from the conventional electronic measurement method.

The majority of fiber-optic sensors that have been researched and developed are based on a method in which the object for measurement is measured point by point, but recently, drawing on the characteristics of optical fiber or optical signal transmission, a sensing technology applicable to multipoint

measurement and distribution measurement has been developed. Whether it is an optical fiber itself or some other sensing element that is used to detect the amount of the object to be measured, the best way to simplify the act of measurement and bring down its cost is to let a single optical fiber carry as much information as possible. Hence, demands have arisen for optical fiber techniques, such as a compound measurement method that enables simultaneous measurement of many kinds of data, a multipoint measurement method that enables simultaneous gathering of data from a broad area, and also a distribution measurement method.

By these methods, a measuring system can be developed that gathers data within a space targeted for measurement all at once and visualizes an unseen object.

(1) Methods of Signal Multiplexing

As for signal multiplexing technology in which signals from various sensors are multiplexed and set over a single optical fiber, when the methods are limited to passive types employing no electronic circuitry in the sensor section, the following are considered: 1) time division multiplexing; 2) frequency multiplexing; and 3) wavelength multiplexing.

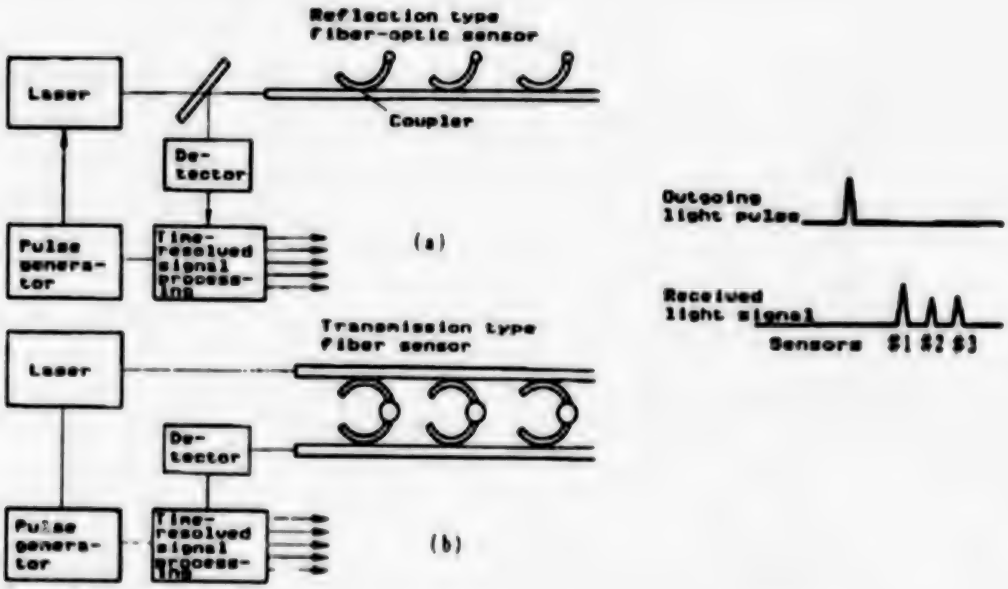


Figure 3. Fiber-Optic Sensor Multipoint Measurement by Time Division Multiplexing

Figure 3 shows the basic principle of a sensor for multipoint measurement based on time division multiplexing. When pulsed light is injected, the time the light reflected (or passed through) from the sensor section needs to reach the photoreceptor differs, so signals from discrete sensors can be separated temporally in the light-receiving section.

(2) Distribution Type Temperature Sensors

Distribution measurement is considered to be a refinement of the multipoint measurement method. This paper describes distribution type temperature sensors based on OTDR (optical time domain reflectometry). OTDR is a measuring method which takes advantage of the phenomenon that when pulse light is injected into an optical fiber, Rayleigh scattering light comes back because of fluctuations inside the fiber whose refractive indexes are smaller than the wavelength, and the intensity of the backscattering light is detected to examine the transmission loss of the optical fiber and its interruptions. The principle is shown in Figures 4 and 5. The transmission loss is determined from the dependency of the intensity of the scattered light on distance, and the distance to the measurement point is determined from the propagation time. Since the intensity of the Rayleigh scattering is dependent on temperature, monitoring the intensity of the backscattering light using OTDR enables measurement of changes in the temperature applied to the optical fiber. Figure 6 shows the results of an experiment. The experiment used a liquid core fiber, a fiber with its core made from a liquid, whose Rayleigh scattering has a large intensity and temperature coefficient. It not only enables observation of changes in temperature but also makes it possible to pinpoint where those changes occurred. It produced a measuring accuracy of 1°C, and a distance resolution of 1 m. Optical fibers with a metal coating have also been tested.

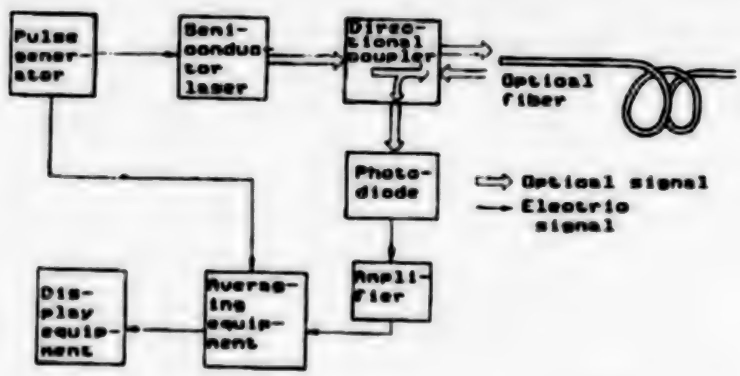


Figure 4. Basic Construction of OTDR

While Rayleigh scattering can be used only for measuring changes in temperature, the use of Raman scattering, scattering caused by waverings of particles of atoms, allows measurement of the absolute value of temperature.

(3) Other Distribution Type Sensors Using OTDR

Two types of sensors have been proposed: one is a distribution type pressure sensor based on the phenomenon that a small bend in an optical fiber increases its transmission loss, and the other is a distribution type oil-leak sensor based on a special optical fiber whose core is altered so

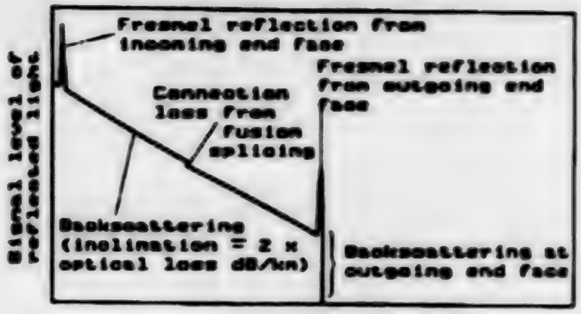


Figure 5. Example of Measurement of Received Signal Levels of Reflected Light

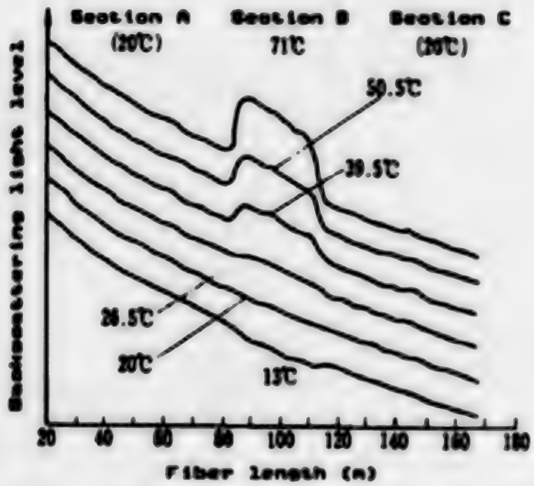


Figure 6. Changes in Backscattering Level by Temperature

that when an oil sticks to the optical fiber, light leaks outside of the fiber, causing its transmission loss to change.

An advantage of fiber-optic sensors using OTDR is that a narrow place or the back of a structure can be observed. They are a measuring method best suited for us in chemical plants with complex structures. Figure 7 shows the concept of the measuring system.

OTDR in optical fibers is comparable to laser radar which is a remote sensing technology of the atmosphere.

The foregoing provides glimpses into the recognition and identification technologies based on optical fiber: one is the technology nearing completion and involves direct transmission of optical images using an optical fiber bundle, the other, a future technology, is the distribution type fiber-optic sensor that captures for measurement an object existing unseen in space.

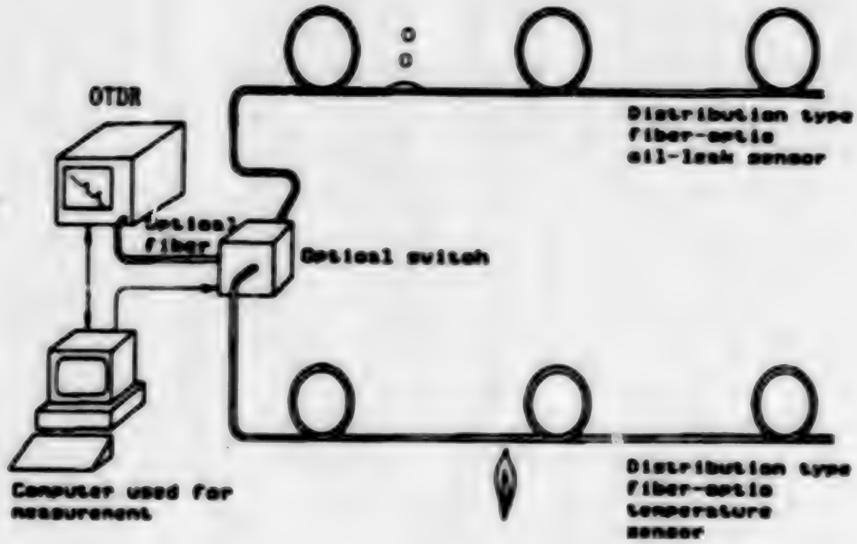


Figure 7. Conceptual Diagram of Multipoint Measurement, and Distribution Measurement

Trends in Ultrasonic Sensors

43064017a Tokyo SENSA GIJUTSU in Japanese Nov 87 pp 29-33

[Article by Kenichiro Suzuki, Industrial Machinery Technology Division, Shimada Rika Kogyo Co.: "Evaluation and Identification of Materials"]

[Text] Ultrasonic waves have long been defined as "sound not for direct hearing by the eras," and they are applied in various fields as sensors as shown in Table 1. In contrast to electromagnetic waves, ultrasonic waves do not propagate through a vacuum and are extremely slow in speed.

These apparent flaws are in fact advantages, and provided with a medium, they propagate through any matter, be it gas, liquid, or solid. Their slow speeds help to raise the relative accuracy in the measurement of time, and they can create with ease sounds of shorter wavelengths. Since ultrasonic waves are a wave phenomenon, they, like electromagnetic waves, show such action as rectilinear propagation, attenuation, reflection, refraction, interference, diffusion, and convergence. The difference is that depending on the kind of medium, there are a plural number of propagation modes characteristic of ultrasonic waves, such as longitudinal wave, horizontal wave, and surface wave.

This article describes two trends in ultrasonic technology in the field of nondestructive testing, a technique for evaluating elastic properties of materials. Both are based on a combination of two types of propagation modes.

Table 1. Uses of Ultrasonic Sensors

Field of use	
Industrial instruments	
Pulse reflection:	Sea level meter; distance meter; surface meter; vehicle sensor
Pulse transmission:	Flow velocity and volume meter; proximity switch; remote control of robot
Transmission:	Ultrasonic switch; gas leak sensor; corona detector
Interference:	Displacement meter; holography
Attenuation scattering:	Densimeter; particle size meter; viscometer
Doppler:	Flow speed and volume meter; speedometer; thermometer
Materials, nature of matter	
Pulse reflection:	Flaw detector; material inspection; microscope
Pulse transmission:	" " " " " "
Transmission:	Acoustic emission; (A.E.)
Interference:	Thickness meter; holography
Attenuation scattering:	Material analysis; hardness meter; crack detection
Doppler:	Thermometer
Ocean, weather	
Pulse reflection:	Depth measuring; fish detector; sonar; tide gauge; snow gauge
Pulse transmission:	Positioning equipment; telemetering; anemometer; pinger
Transmission:	Underwater communication; sonar; listening device
Interference:	Holography; fish type identifier; FM; sonar
Attenuation scattering:	Densimeter; fish school-size meter; densimeter
Doppler:	Wind direction and speed meter; ship navigator; tidal current meter; doppler sonar
ME	
Pulse reflection:	Ultrasonic diagnosis; CT; microscope; cardiography
Pulse transmission:	Ultrasonic diagnosis; CT
Transmission:	Ultrasonic diagnosis; phonocardiograph
Interference:	Holography, aid to the blind; microscope
Attenuation scattering:	Dialysis bubble detection; monitoring of blood transfusion
Doppler:	Blood flow meter; monitoring of fetal heartbeat

[continued]

[Continuation of Table 1]

Field of use	
Others	
Pulse reflection:	Delay line; existence sensor
Pulse transmission:	Delay line; burglar alarm
Transmission:	Delay line; filter
Interference:	Modulator; burglar detection
Attenuation scattering:	Liquid-leak detection
Doppler:	Speed detection

1. Macro Evaluation and Identification

It is an application of the ultrasonic flaw detection method, but in the case of simple visualization of flaw probing, the technology is at a stage of practical use owing to the resolving power enhancement techniques such as the aperture synthesis method and CT, but it is not described in this paper.

When an ultrasonic pulse is made to pass through a solid, provided the density is ρ, the elastic coefficient E is obtained from the following equation:

$$E=3\cdot\rho\cdot C_s^2\cdot\frac{(C_d^2-(4/3)C_s^2)}{(C_d^2-C_s^2)} \quad \cdots\cdots(1)$$

where,

C_s: horizontal wave propagation speed = l/t_s
C_d: longitudinal wave propagation speed = l/t_d

and,

l : thickness of sample
t_s: horizontal wave propagation time
t_d: longitudinal wave propagation time

Poisson's ratio ν can be obtained from the following equation:

$$\nu=\frac{1}{2}\cdot\left\{1-\frac{1}{(C_d/C_s)^2-1}\right\} \quad \cdots\cdots(2)$$

In materials in which Poisson's ratio is considered uniform, the coefficient of elasticity can be expressed by the longitudinal wave speed alone as shown in the following equation:

$$E=\frac{(1+\nu)(1-2\nu)}{(1-\nu)}\cdot\rho\cdot C_d^2 \quad \cdots\cdots\cdots\cdots(3)$$

If the density, Poisson's ratio and thickness are known in advance, the coefficient of elasticity can be calculated from the propagation time of the longitudinal wave alone.

Figure 1(a) shows a system block diagram of material testing equipment for measurement of the coefficient of elasticity, and Photo 1 [omitted] shows its external appearance. In the system, to make it possible to take measurements of a large number of points on a two-dimensional plane, XY coordinates and the thickness of Z are input, along with the elasticity data (propagation time and amount of attenuation), into a computer for computation.

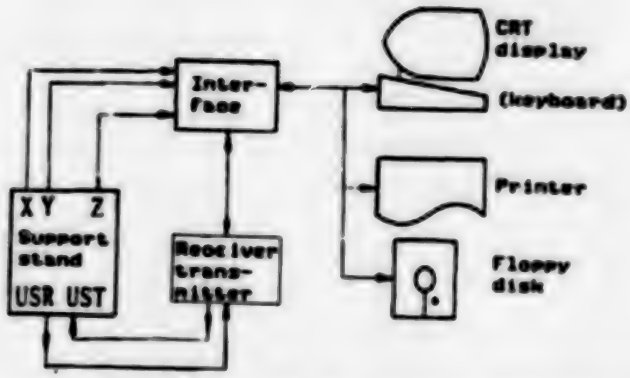


Figure 1. Block Diagram of Material Testing Equipment

Figure 2 shows a case of measurement taken of an inferior quality grinding stone (WA60 kV), a porous material. Figure 2(a) is a two-dimensional display in color, and Figure 2(b) is a three-dimensional display. There is seen a relatively good correlation between the coefficient of elasticity and the amount of propagation attenuation. Since the unevenness in the direction of the circumference was a pattern leading to destruction by mechanical stresses, the quality of the grinding stone could be determined by elasticity data along the circumference alone.

Figure 3 shows measurements of silicon nitride (100 x 100 x 15), a ceramic, sintered at normal temperature. Because it is a propagation time display, the central portion, where time is large, is small in the coefficient of elasticity. In this case, the propagation attenuation was also small. Materials with a large coefficient of elasticity generally tend to have less attenuation. The method of measuring the coefficient of elasticity of ceramics is standardized under JIS.

These measurements are conducted using samples that have not been immersed in water, so when measuring porous materials, adhesive tape or rubber is used as the coupling material, and when those materials have a mirror-surface, jelly, oil or honey is used.

Thin materials or porous materials can be measured by using an air coupling that protects the sample from coming into contact with the transducer.

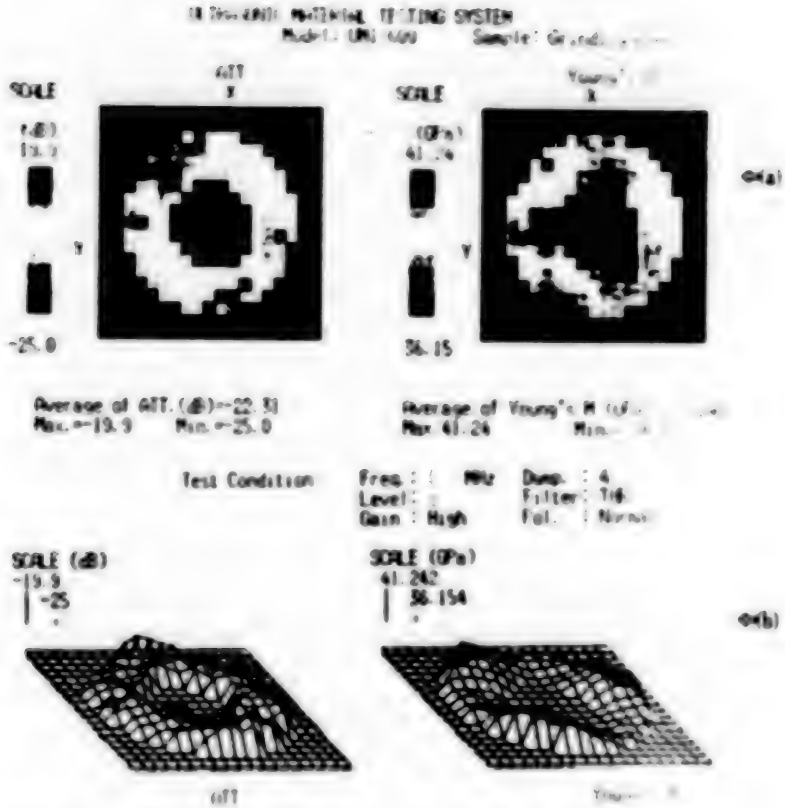


Figure 2. Outputs of Measurements of Grinding Stone
(a) Two-dimensional display
(b) Three-dimensional display

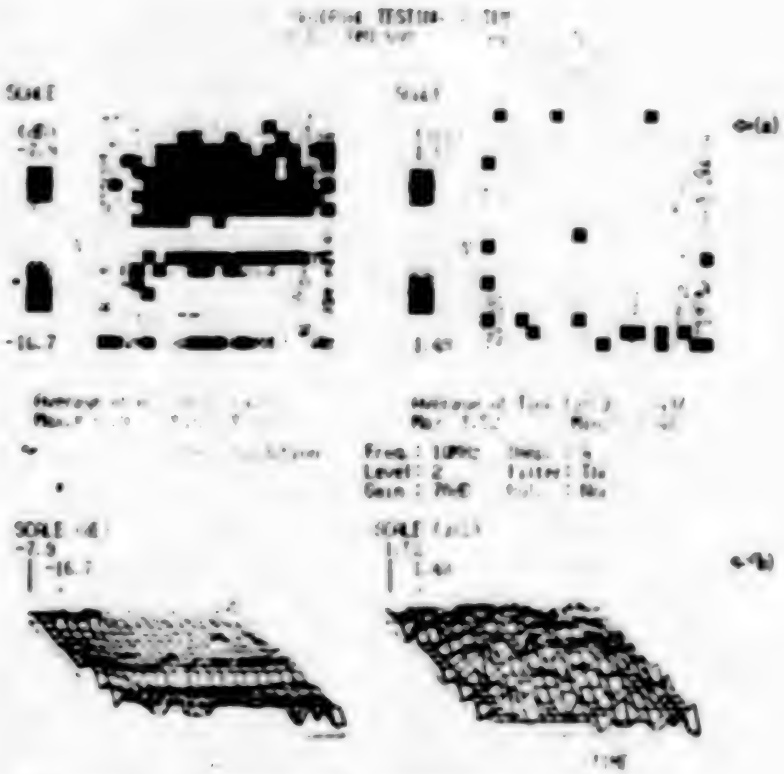


Figure 3. Outputs of Measurements of Si_3N_4
(a) Two-dimensional display
(b) Three-dimensional display

Figure 4 shows measurement of a calcium silicate board. Since the propagation time of the ultrasonic wave through air is added, it is difficult to measure the absolute value. On the other hand, since the speed of sound in the air is dependent on temperature, compensation will have to be made.

So long as the materials for measurement permit ultrasonic waves to pass through them, the technique can be applied to any kind of material including metals, ceramics, plastics, carbon, and composite materials like FRP. A special case involves management of reactions of medical fluids by the ultrasonic pulse method.

The material testing system achieved a time resolution of 0.1 ns and a damping amount of 0.1 dB, and [illegible] use transducers of 10 kHz to 50 MHz range. Since the vibrating p[illegible] relatively large, from $\phi 6$ to $\phi 30$, and since the transmission method is [illegible] basic method, the evaluation and identification must be called macroscopic.

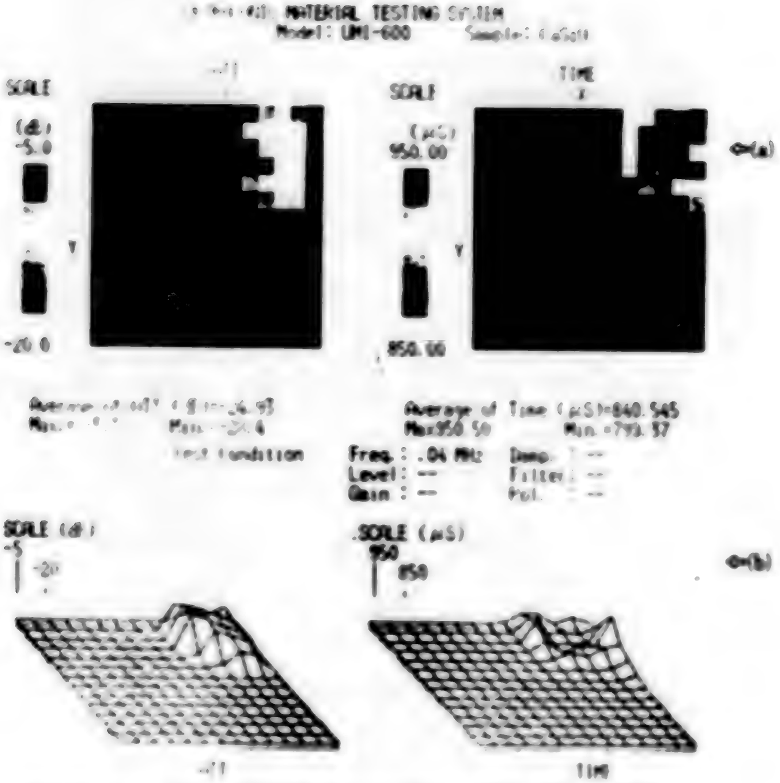


Figure 4. Outputs of Measurements of Ca_2SiO_3
(a) Two-dimensional display
(b) Three-dimensional display

2. Microscopic Evaluation and Identification

The technique is an application of ultrasonic microscopes. In this paper, the author will not take up simple image recognition but will describe the $V_{(z)}$ curved line method necessary for quantitative evaluation and recognition of elastic characteristics.

In a reflecting type ultrasonic microscope, when only the distance between a sample and the acoustic lens Z is altered, the output levels of the transducer register a maximum and a minimum at a cycle of a fixed distance, as is shown in Figure 5(a). This is called a $V_{(z)}$ curve. When employing the signs used in the diagram explaining the principle in Figure 5(b), the curve is generated by the interference between the vertical reflection element (E-F) from the sample surface and the re-radiation element of the leakage elastic surface wave that has been excited at a critical angle of θ_{LSAW} at the boundary between the water and the sample (A-B-C-D-E), and measuring of the cycle of the Z axis makes it possible to evaluate and identify the elastic characteristics of a solid material. Figure 6 shows the block diagram for the reflecting type ultrasonic microscope.

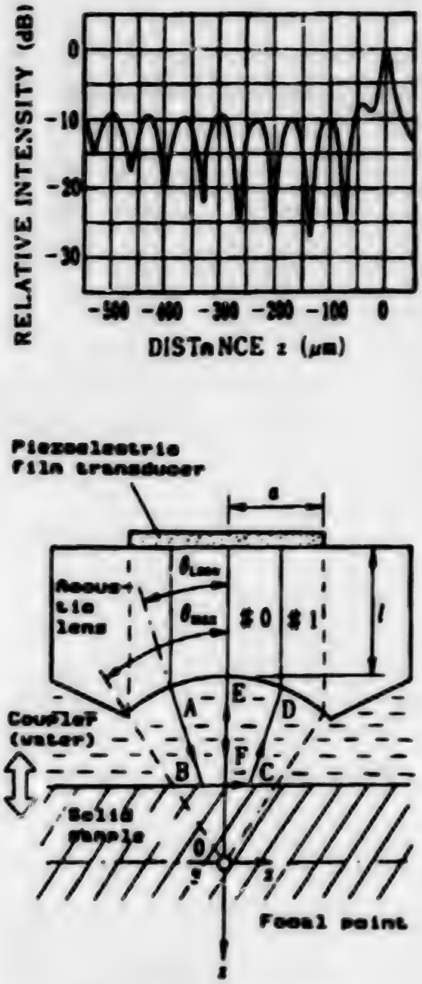


Figure 5. (a) $V_{(z)}$ Curve on Si Single-Crystal (111) Surface (225 MHz, propagation in the direction (110)
(b) Diagram Explaining Principle of Formation of $V_{(z)}$ Curve

Figure 7 shows the results of a measurement of a ceramic wafer (PZT). The wafer is used as the material for filters. The acoustic velocity measurement evaluation and identification that has an impact on the resonance frequency has become available at the stage of wafer, thus contributing to improved quality control. In taking measurements, water is used as a coupler in most cases and its physical properties are used as a reference, so the temperature control of liquids, along with the stability of the Z axis, is important. THe relative acoustic velocity precision has been below ±0.05 percent.

The ultrasonic microscope covers the 50 MHz-3 GHz zone, but as the wavelength becomes shorter, the effect of the unevenness of the surface of

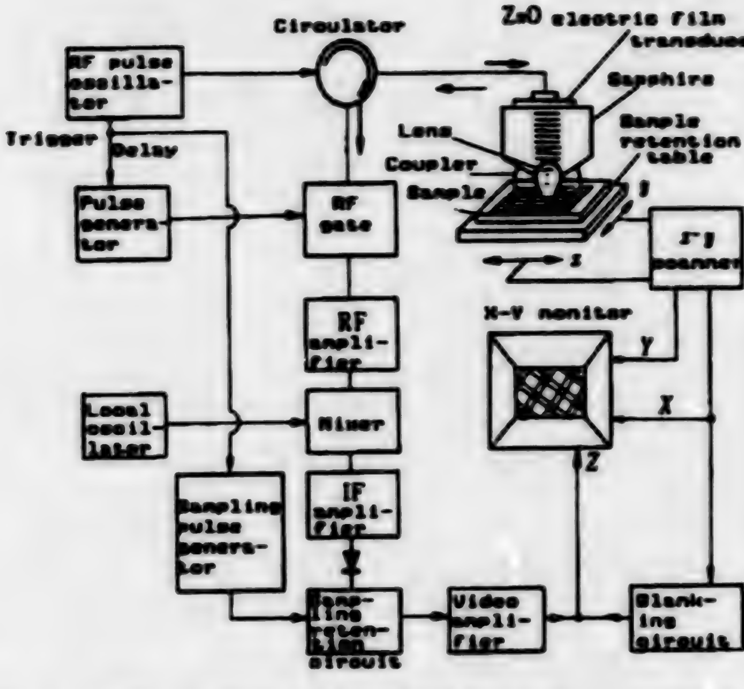


Figure 6. Block Diagram of Reflection Type Ultrasonic Microscope

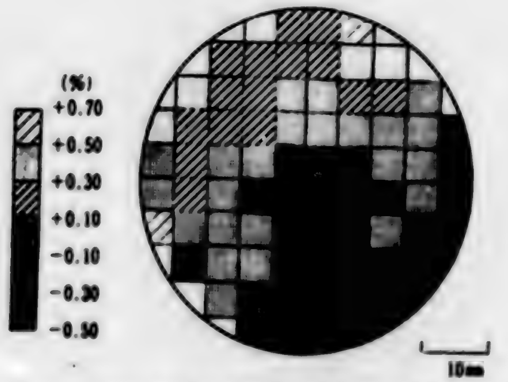


Figure 7. Two-Dimensional Distribution of Sound Speeds of Leakage Elasticity Surface Wave on PZT Wafer

a sample cannot be ignored. Micro evaluation and identification have their share of difficulty. The acoustic velocity measurement scope can be applied broadly to materials from polymer to diamond.

The foregoing is a glimpse into the method of evaluating elasticity characteristics peculiar to ultrasonic waves. The scope of use of ultrasonic flaw detectors and ultrasonic microscopes has greatly expanded as a result of achieving visualization, and the hardware may be said to be

completed. The way from quantitative evaluation to identification requires accumulation of a large number of discrete data bases, so the technique has just begun to be put to practical use. Development of software including high-speed statistics processing and recognition algorithms is awaited, and at the same time efforts are needed to transform the ultrasonic measurement technique from the mainstay batch process to the in-line process.

20114/9365

VLSI Process Technical Trends Described

43065051 Tokyo DENSHI ZAIRYO BESSATSU in Japanese Nov 87 pp 3-8

[Article by Dr Yasuo Tarui, professor, Electronic Engineering Department, Faculty of Engineering, Tokyo University of Agriculture and Engineering]

[Excerpt] **Limit of MOS Device Miniaturization**

Up to now, large-scale integration has developed with the silicon MOS device as the mainstream, and this is expected to continue for the next decade. CMOS will be increasingly used, and Bi-CMOS which contains a bipolar integrated circuit will be used for high-speed operation.

Since memory does not become very complex even if the design is of high integration, it is easy to use in the application of a new process technique, and it has been the pulling force of miniaturization process development. It is also thought that this will remain the same for the next decade.

On the other hand, development of the ASIC (application specific IC) to adapt to diversified demand and to obtain high added value will be given great importance. A process technique confirmed by memory will also be applied to the ASIC field in a few years, and it is thought that many kinds of highly integrated ASICs will appear.

The development of integration, therefore, where the miniaturization limit pertains to the behavior of the MOS transistor, the main device, becomes important basic data. many estimates have been made so far about the limits of miniaturization, and most of them have already been exceeded. Formerly, Wallmark[1] estimated on the basis of many simplification assumptions that the limit of device simplification was in general several microns. At the time, this value was thought to be sufficiently small.

Even 2 or 3 years ago, many people set the limit of light lithography at 0.5 μm and development of main devices at about the same limit. These limits are also being exceeded. With regard to the limit of the MOS transistor, Mead, et al., estimated at 0.24 μm the minimum channel length based on an invertor circuit using an enhanced-type MOS transistor on the basis of several assumptions.[2] This estimate was also considered sufficient as a limit and was thought to have excellent prospects at the

time of announcement, but now it appears that the assumptions as to the methods of determining device structures, circuits, voltage, and insulation films were not investigated sufficiently.

At present, a channel length of 0.25 μm is thought of as a surely realizable target rather than as a limit. In other words, the channel length is being studied at present as a so-called quarter micron supersuper LSI technique, and a design method[3] in this field has been made public.

Thus, history seems to show that it is not worthwhile to set limits precisely using the assumptions of an earlier period, because new ideas appear outside the range of such thinking that exceed those limits, and it seems that this process occurs repeatedly.

The minimum dimension of the MOS transistor channel length is discussed as an important quantity for the miniaturization limit. Some structures are such as to make a decision on the dimension of the channel length difficult. A study of these structures suggests that the junction depth should be made negative (minus) because the channel effect becomes larger as the depth of the junction of source and drain becomes deeper.

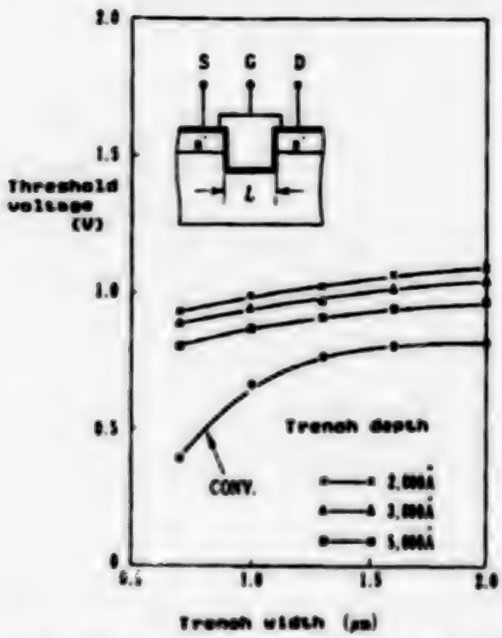


Figure 1. Trench Width Dependency of Threshold Voltage of MOS Transistor Using Trench as Channel[4]

For example, for the 4M RAM, NEC Corp. recently announced the trench-type transistor shown in the insert in Figure 1.[4] In this case, the short channel effect is improved, as shown in Figure 2, in response to the junction depth being a negative value. In the same way, both the narrow channel width effect and the subthreshold effect are sharply improved. All these effects can be considered as factors of the miniaturization limit.

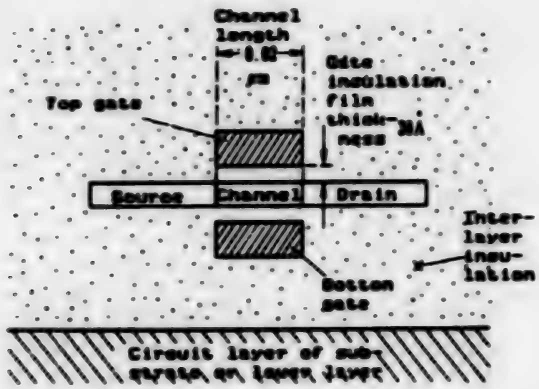


Figure 2. XMOS Transistor With Thin Silicon Layer and Double Gate Structure

Electrotechnical Laboratory announced a transistor with the structure shown in Figure 2, called the XMOS transistor, as a structure which dramatically improves the short channel effect.

The three items generally listed as short channel effects are: 1) a drop in threshold value voltage; 2) a drop in the withstand voltage between source and drain; and 3) a deterioration in subthreshold characteristics. Items 1) and 2) occur with the influence of drain electric field on the source neighborhood and item 3) occurs with a drop in the efficiency with which punchthrough and gate voltage excite movable charges.

The XMOS transistor shown in Figure 2 is provided with gates at the top and bottom, increased substrate impurity density, and thinner silicon thickness in the channel area so that all of the semiconductor films of the channel group are depletion layers when semiconductor surfaces are inverted. In this way, the minimum dimension of the XMOS is estimated at 0.02 μm, as indicated in Figure 2.

Perhaps the safest limit will be obtained by the Landauer theory,[6] which assumes neither circuit nor device to require an kT-order energy for each operation of information processing.

On the other hand, another question is how far miniaturization is effective. So far, miniaturization has been able not only to integrate many elements on graphics but also to enhance characteristics of transistors, to allow integration without dropping electric functions. That is, what makes up for the increase in wiring capacity brought by integration is improvement of gm.

Experimental results have been reported on how the gm value for the unit channel width increases as the channel length decreases.[7] According to this report, even for an MOS transistor using bulk memory, gm continues to increase until the effective channel length approaches 0.1 μm, and the saturation of gm has not been caused yet by the saturation of electron speed.

Prospects of Increase in MOS Memory Integration

As mentioned above, memory has always been the pulling force of new process development. Of memory units, the DRAM, which has a small number of elements per bit and allows the highest integration, was developed first of all and it is an index showing the trend of IC. Therefore, the DRAM will be described first.

Figure 3 provides a forecast in the increase in integration for the next decade. The increase is based on the prospects and possibilities related to the above-mentioned MOS transistor structure miniaturization and prospects of lithography. This forecast may change a little because of the severe competition, but the general trend is thought to be as shown in this illustration. The forecast design rule is 0.5 to 0.7 μm for the 16M DRAM, 0.3 to 0.4 μm for the 64M DRAM, and 0.2 to 0.3 μm for the 256M DRAM, approximately.

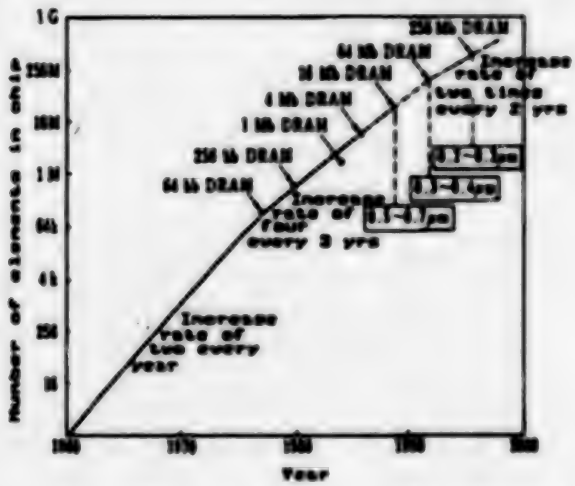


Figure 3. Annual Change and Forecast of Number of Elements Per Chip

With regard to the DRAM, various ideas are used to keep the memory capacitance value even in miniaturization, and authors also are studying a manufacturing method which yields a tantalum oxide film that is manufactured in an optical process and whose permittivity and voltage-withstand characteristics are three to four times larger than those of a thermal silicon oxide film.[8] In some cases, weight is transferred to the gain cell or SRAM after various ideas have been put forward, but Figure 3 shows the number of integrated elements on the ordinate and can be considered as the general trend.

Lithography Development Lead by Excimer

The article cited previously mentioned that the prospects of lithography were being anticipated because of lithography based on the narrow-band excimer laser announced by Bell Laboratories in March last year. The

development since that time appears to be advancing clearly in the direction forecast. In general, resolution R and focus depth d of a lens are given by the following expressions:

$$R = \beta \frac{\lambda}{NA} \tag{1}$$

$$d = \pm \frac{\lambda}{2(NA)^2} \tag{2}$$

where, λ: exposure wavelength,

NA: numerical aperture of lens. NA = sinθ, where θ is the aperture angle of the light incident on a wafer.

β: theoretical limit. Usually, 0.5 is used as the theoretical limit and actually, the value about 0.8 is used.

To raise resolution, therefore, the shortening wavelength λ is most effective. To shorten a wavelength, however, the problem of lens material has to be resolved. To be more specific, if light wavelengths extend over a range such as in the case of a lamp light source, the light that passes the lens causes chromatism. To prevent chromatism, multiple materials of different refractive indexes have to be combined to perform so-called "achromatism."

Synthetic quartz is a single material which transmits light whose wavelengths go up to about 180 nm, as shown in Figure 4. However, since easy-to-use other materials are difficult to obtain, achromatic optical lenses have been considered to be usable for practical purposes as far as up to an about 300 nm wavelength.

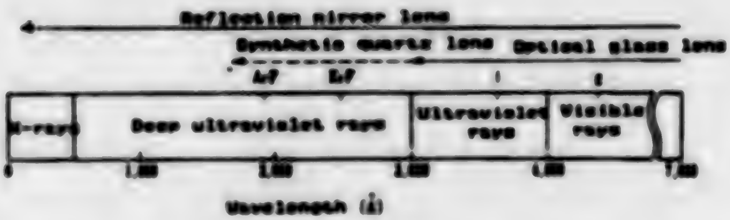


Figure 4. Light Wavelengths Used for Transcription Device

Now, development of the excimer laser, which can generate strong light of short wavelengths and a comparatively narrow wavelength width, has come to break the wavelength limit of optical lenses.

An announcement[8] by Mr Paul, et al., at AT&T's Bell Laboratories pointed to a definite narrowing of the wavelength width which is the cause of chromatism. The excimer laser itself has a narrow wavelength width. A wavelength depends on the gas used, and in the case of the KrF which was used, the wavelength is 248.8 nm and the wavelength width is 0.8 nm.

Bell Laboratories eliminated the cause of chromatism by decreasing the wavelength width two positions, to 0.007 nm, and made possible a lens system using only quartz; it succeeded in decreasing the wavelength limit to the position shown in Figure 4 for the synthetic quartz lens. Figure 5 shows the projection optical system.[11] Here, the mirror shown as the scan mirror is used to prevent the appearance of speckles caused by light interference through changing the light path by making the angle variable.

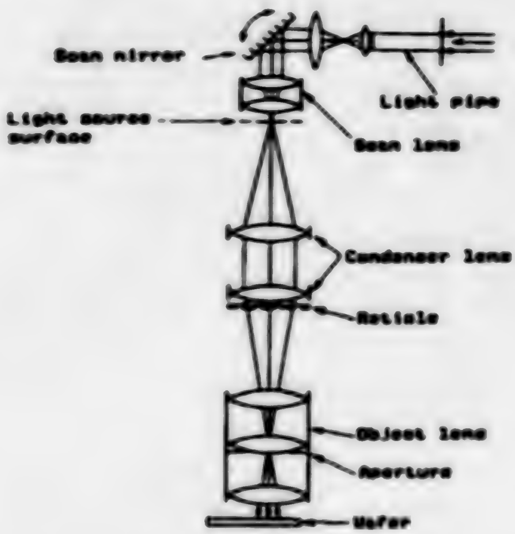


Figure 5. Projection Optical System of Excimer Laser Lithography[11]

In the announcement, it was stated that in order to narrow the wavelength width, an etalon which works as a band filter was inserted into the light path. In December last year, however, the use of an injection-synchronizing excimer laser reduced exposure time to 3s by strengthening light intensity by making the original wavelength width 0.005 nm.

At a VLSI symposium which was held in Karuizawa in May this year, Mr Paul gave a lecture by invitation at which he introduced many clear exposure patterns. The recent adoption of a 200 Hz narrow-band excimer laser reportedly has brought about easier laser maintenance, such as replacement of gas for every 10^7 pulses, routine maintenance for every 10^8 pulses, and major maintenance for every 10^9 pulses.

Table 1 indicates the future development prospects for the excimer laser stepper shown at the lecture. Such progress in the stepper is thought to be the basis for the integration development indicated in Figure 3.

Research and development related to excimer laser lithography is also being put forward and made public in this country by Toshiba Corp. and Matsushita Electric Industrial Co., Ltd. From the beginning, Toshiba seems to have put development forward with a color correction method. Matsushita Electric Industrial Co., Ltd., which was aiming at the narrow band with the

Table 1. Future Prospects of Excimer Laser Stepper Development

Item	Value			
Wavelength (nm)	248	248	193	193
NA	0.38	0.5	0.38	0.5
Field diameter (mm)	20	15	20	15
Resolution (μm)	0.4	0.3	0.3	0.23
Focus depth	±0.8	±0.5	±0.6	±0.4
Year	1990	?	1994	?

etalon, further developed a new water-soluble photopolymer (WSP-EX) for the excimer laser as a measure for shallower focus depth due to shorter wavelength in order to supply a means of contrast-enhanced lithography (CEL).

Figure 6 shows the bleaching characteristic of WSP-EX. That is, the solid line characteristic before light incidence has had its transparency greatly increased by exposure to a 245 nm excimer laser. In other words, use of this polymer as the topmost surface layer can raise the exposure contrast of lower-layer resists.

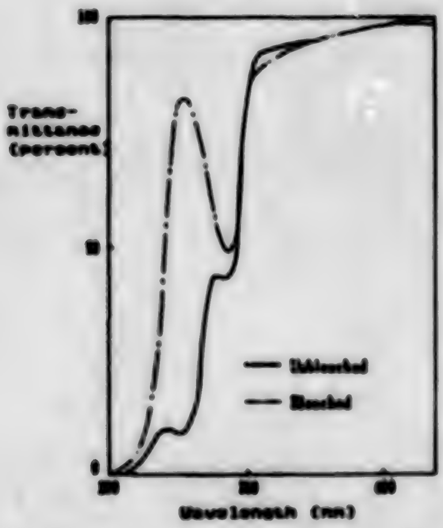


Figure 6. UV Spectrum Characteristic of Water-Soluble Photopolymer (WSP-EX) Before and After Light Radiation[13]

At the lamp session of the VLSI symposium in May this year, Matsushita Electric Industrial Co., Ltd., introduced a compact excimer laser that is being developed in cooperation with other companies. The size is

approximately 1 x 0.3 x 0.5 m including the etalon--quite small compared to the conventional size. The repeat frequency is aimed at 500 cps, and the company appears to anticipate no speckle problem. Based on the needs of the excimer stepper, the trends of miniaturization and pursuit of higher capability and higher reliability of the excimer laser are making rapid progress.

Apart from this progress in the transcription device, the beam technique used for drawing is also showing progress. The electron beam drawing device, which has been used for drawing for some time, has been made increasingly smaller and more high speed. The ion beam is capable not only of ion injection, etching, and deposition CVD in a maskless state, but also of small vicinity effect because of the small scattering effect in lithography. Furthermore, it is attracting attention because its sensitivity is better by two positions than that of the electron beam, and many experimental results have been reported in GaAs-related materials.

At the same time, the use of ion beams for drawing devices is also making steady progress. At the SPIE symposium in March this year, a 150 kV convergent ion beam drawing device with the same automatic drawing system as that of the electron beam drawing device was announced,[14] and this year a similar device accelerated to 200 kV was announced in the same society.[15] Each of these has a liquid metal ion source and allows beam current of about 100 pA for a 0.1 μm probe diameter.

Along with the development of these devices, it seems that the ion beam is being put to practical use, beginning with uses that fully utilize its advantages. Further expansion of uses of the ion beam depends on development of an ion source that is maintenance free, an alignment method for positioning when the ion range is short, and high-speed scanning.

Superclean Technique to 0.1 μm

Another item that is important for advancing development into the submicron area, especially into the area of 0.5 μm or less, as indicated in Figure 3, is related to cleanness. For production, the cleanness most effective for each dimension has to be obtained. To achieve such cleanness, it is necessary to have a clean room of sufficiently high cleanness, a gas system, chemicals, and all other required materials.

Pursuit of superclean technology has been undertaken here in order to attain high-level cleanness and high quality in a broader area; a superclean room system, etc.[16] has been announced and is attracting attention.

When a superclean room is constructed, not only is the aim to achieve high-level cleanness but also the rapid recovery of cleanness when a clean room is closed and reopened, suitable for R&D at universities. Figure 7 shows the experimental values. That is, dust is found to reach zero count in about 4 minutes if the air conditioner is restarted after being stopped for 4 hours and dust of 0.17 μm or more has reached the level of $2 \times 10^6/ft^3$.

Figure 7. Cleanness Recovery Characteristics of Superclean Room[16]

The yield drop by dust is said to be caused by static electricity in many cases. In this superclean room, all of the surfaces which clean air contacts are made conductive and grounded. The sheet resistance is $10^{6}\Omega/\ell$ in a clean room and $10^{9}\Omega/\ell$ in the areas underneath the flour and above the ceiling. This arrangement keeps the potential of all the surfaces in a clean room at 6V or less.

The temperature control in a lithography room is kept within a precision of ±0.1°C. This precision is realized by installing a precision temperature control unit on the filter unit in the area above the ceiling and sending temperature-controlled clean air into the room.

To reduce vibration in the clean room, the clean room and the air conditioner room are separated except in the case of the area underneath the floor. The various ducts and pipes linking these two rooms are connected by flexible joints. A place where vibrations of frequencies 3 Hz or more are 0.2 to 0.3 μm has been selected on the campus, a 1-m thick and 1,150 m^2 concrete floor has been constructed using 2,150 tons of concrete, and the clean room has been constructed on the floor. As a result vibrations of 3 to 10 Hz are suppressed to 0.5 μm or less.

A highly pure gas supply system has also been developed.[17] The achievements realized in this system are: an absence of particles, the external leak quantity is equal to or less than 1×10^{11} Torr·ℓ/s·cm^2, the discharged gas from pipe walls is equal to or less than the same detection limit, the various impurities are equal to or less than several ppb, and the water is equal to or less than 5 ppb at the use point. The highly pure gas supply system has been developed by giving attention to many related parts: 1) careful investigation of internal materials of the gas supply system; 2) mirror processing of pipe wall surfaces; 3) elimination of the

dead zone where gas stops; and 4) elimination of movable parts inside the gas supply system to prevent particles from occurring.

New manufacturing devices are also being developed following the development of the clean room. For example, a bias sputtering device in the RF-DC connection mode is in a developmental stage.[18] With this device, the target voltage is selected so as to maximize separating speed and the substrate bias is set so as to achieve the highest film quality.

Hereafter also, new process techniques are expected to be developed in this superclean room.

Bibliography

1. J.T. Wallmark, "Basic Consideration in Microelectronics," edited by E. Keonjian, McGraw-Hill, 1963, p 10.

2. B. Hoeneise and C.A. Mead, "Fundamental Limitations in Microelectronics," MOS TECHNOLOGY, SOLID-STATE ELECTRONICS, Vol 15, 1972, p 8197.

3. G. Baccarani, M.R. Wordeman, and R.H. Dennard, "Generalized Scaling Theory and Its Application to a 1/4 Micrometer MOSFET Design," IEEE TRANS. ELECTRON DEVICES, Vol Ed-31, No 4, April 1984, p 452.

4. M. Yanagisawa, K. Nakamura, and M. Kikuchi, "Trench Transistor Cell With Self-Aligned Contact (TSAC)," IEDM, No 66, 1986, p 132.

5. T. Sekigawa and Y. Hayashi, "Calculated Threshold-Voltage Characteristics of an XMOS Transistor Having an Additional Bottom Gate," SOLID STATE ELECTRONICS, Vol 27, No 8-9, 1984, p 827.
   Hayashi, "Megabit-Class Integration Dream," NIHON NO KAGAKU TO GIJUTSU, Vol 27, No 242, 1986, p 46.

6. R.W. Laudauer, "Irreversibility and Heat Generation in the Computing Process," IBM J. RES. DEVELOP., Vol 5, 1961, p 183.

7. S. Horiguchi, T. Kobayashi, M. Miyake, M. Oda, and K. Kiuchi, "Extremely High Transconductance (above 500 mS/mm) MOSFET With 2.5 nm Gate Oxide," IEDM, No 85, 1985, p 701.

8. Y. Tarui, S. Oka, M. Matsui, K. Yamagishi, and K. Kuroiwa, "Photo. CVD of Tantalum Oxide Films and Their Characteristics," Extended Abstr. of the 19th Conf. on Solid State Devices and Materials, Tokyo, 1987, p 219.

9. V. Pol, J.H. Bennewitz, G.C. Escher, M. Feldman, V.A. Firtion, T.E. Jewell, B.E. Wilcomb, and J.T. Clemens, "Excimer Laser-Based Lithography; a Deep Ultraviolet Wafer Stepper," Proceedings of SPIE's Santa Clara Symp. on Microlithography, No 633, March 1986, p 6.

10. J.H. Bennewitz, G.C. Escher, M. Feldman, V.A. Firtion, T.E. Jewell, V. Pol, B.E. Wilcomb, and J.T. Clemens, "Excimer Laser-Based Lithography for 0.5 μm Device Technology," IEDM No 86, 1986, p 312.

11. V. Pol, J.H. Bennewitz, T.E. Jewell, and D.W. Peters, "Excimer Laser Based on Lithography: A Deep-Ultraviolet Wafer Stepper for VLSI Processing," OPTICAL ENGINEERING, Vol 26, No 4, 1987, p 311.

12. V. Pol., J.H. Bennewitz, and J.T. Clemens, "0.5 μm Device Processing With Excimer Laser-Based Lithography," 87 Symp. on VLSI Technology, DIGEST OF TECHNICAL PAPERS, 1987, p 1.

13. M. Endo, H. Nakagawa, Y. Hirai, M. Sasago, K. Ogawa, and T. Ishihara, "Advanced Excimer Laser Lithography," Ibid., 1987, p 5.

14. R. Aihara and H. Sawaragi, "Achievements of Recent Research in Focused Ion-Beam Technology," Proceedings SPIE's 1987 Santa Clara Symposium on Microlithography, Vol 632, Electron Beam, X-ray, and Ion Beam Techniques for Submicrometer Lithography V, 1987, p 196.

15. R. Aihara, H. Sawaragi, H. Morimoto, K. Hosono, Y. Sasaki, T. Kato, and M.H. Shearer, "A Focused Ion-Beam System MIBL-200s With a New Optic Design Concept," The 31st Intl. Symp. on Electron, Ion, and Photon Beams, No 5, 1987.

16. T. Ohmi, N. Mikoshiba, and K. Tsubouchi, "Super Clean Room System-Ultra Clean Technology for Submicron LSI Fabrication," presented at the First Intl. Symp. on Ultra Large-Scale Integration, Sci. and Tech. (the Electrochemical Society), which was held at Philadelphia, Pennsylvania on 10-15 May 1987, and will be published in the proceeding volume.

17. T. Ohmi, J. Murota, Y. Kanno, Y. Mitsui, K. Sugiyama, K. Kawasaki, and H. Kawano, "Ultraclean Gas Delivery System for ULSI Fabrication and Its Evaluation," Ibid.

18. T. Ohmi, H. Kuwabara, T. Shibata, and T. Kiyota, "RE-DC Coupled Mode Bias Sputtering for ULSI Metallization," Ibid.

20111/9365

Status of X-Ray Lithography Devices Examined

43065052 Tokyo DENSHI ZAIRYO BESSATSU in Japanese Nov 87 pp 92-98

[Article by Nobuji Atoda, chief, Beam Application Laboratory, Electronic Device Department, Electrotechnical Laboratory]

[Text] X-ray exposure theoretically has many superior features compared with light exposure, and it has been studied as a post-light-exposure technique. However, the light exposure technique has been enhanced in resolution, causing the X-ray exposure's turn to be successively postponed. A recent report[1,2] that patterns of about 0.35 μm can be formed with reduced projection exposure using the excimer laser as the light source suggests that the X-ray exposure technique has reached the stage wherein its position should be reconsidered.

Of course, light exposure does not seem to lend itself easily to a high-precision, high-throughput, and high-yield process in an area where the pattern width is 0.5 μm or less. Unlike an area where the pattern width is up to about 1 μm, an area where the pattern width is 0.5 μm or less does not allow a lens system to have any margin in its resolution, focus depth, and field size, and furthermore, use of a multilayer resist seems unavoidable, making the process more complex.

On the other hand, X-ray exposure has the advantage that it poses few such problems, allows high-precision minute pattern transcriptions with a single-layer resist, and causes few exposure defects to occur with dust. For practical use, however, X-ray exposure presents many challenges, such as attainment of a highly bright beam source and establishment of techniques for the creation, inspection, and modification of a mask. Furthermore, economical efficiency and adaptability to existing processes will be required for X-ray exposure to replace light exposure. If the present developmental stages of light and X-ray exposure are taken into consideration, many people are strongly of the opinion[3] that light exposure will be used up to 0.5 μm and possibly on up to 0.35 μm.

Therefore, X-ray exposure urgently needs to develop a technique that will enable it to compete with light exposure in the area of 0.5 to 0.35 μm and a technology that is applicable in the area of 0.25 μm or less where light exposure is thought to be difficult to use. What is thought of as the prospective winner is the emissive light (synchrotron-emissive light)

exposure technique, but it is at a state wherein small accumulation rings are in the developmental stage, and some time will pass before the technique can be put to practical use. Also, an equal-sized transcription technique is not easy to establish for the area of 0.25 μm or less, and not only6 enhancement of conventional techniques but also investigation of new methods such as reduced projection and research and development in more basic stages will be necessary. The time frame for these activities will be two to three generations of integration transition if light exposure is used up to 0.35 μm.

In this article, therefore, X-ray exposure technique aimed at the area of 0.5 to 0.25 μm will be outlined, with emphasis on the present state.

X-Ray Lithography Devices

In 1986, the U.S. Micronics Corp. put on the market an X-ray stepper as an 0.5 μm device, and Nippon Kogaku K.K. and Perkin Elmer Corp. also each announced a similar device. These devices are not described in detail in this article because they were introduced in last year's handbook,[4] but since each of them uses an electron-beam-exciting-type beam source, the throughput is low (10 sheets of 6-inch wafers/hour, approximately). Besides, since the throughput was evaluated on the assumption of using a highly sensitive resist, which is thought of as having weak points in resolution and dry etching resistance, the use of such devices will be limited. Incidentally, Micronics Corp. is said to have gone bankrupt recently.

As subsequent new activities, a stepper that mounts a plasma X-ray source and an emissive light stepper are introduced here. Both devices were reported at the SPIE Symposium held in March 1987.

1. Stepper Mounting Plasma X-Ray Source

NTT started grappling early with the development of X-ray exposure techniques, and in 1982 it announced the SR-1 (of an electron-beam-exciting-type-beam source), which was the first 0.5 μm X-ray stepper in the world.[5] The company advanced development of an alignment method[6] and a gas-puff-type plasma X-ray source,[7] and it integrated these element techniques at that time to announce them as a stepper system.[8] Table 1 gives the specifications of this device, Figure 1, the configuration of the aligner part, and Figure 2 the structure of the X-ray generating part.

The X-ray generating part is provided with several new ideas that make it different from the conventional product. First, the electrode material in the plasma generating room has been replaced by tungsten and it has further been made hollow to prevent discharge current from concentrating upon the electrode surface, reducing wear of the electrode and creation of debris. The plasma remover has been provided with a new high-speed valve, and the use of a gas curtain to prevent the neutrons, high-energy ions, and short-wavelength ultraviolet rays from passing part of the magnetic field and reflective plate enhances the life of the window material on the downstream

Table 1. Specifications of Stepper Mounting Plasma X-Ray Source

(a) Performance	
Minimum line width	0.5 μm
Throughput (Field 9 - 30 x 30 mm) (Resist sensitivity 80 mJ/cm²)	20 wafers or more/hr
Superposition precision	±0.15 μm/20 x 20 mm (2 σ)
Field dimensions	15 x 15 mm - 30 x 30 mm
Wafer dimensions	4 - 6 inches
(b) Alignment	
Alignment method	Single diffraction grating and double-pitch double diffraction gratings
Detection resolution (Gap and positional discrepancy)	0.01 μm
Alignment precision	±0.05 μm (2 σ)
Gap setting precision	±0.03 μm (2 σ)
(c) X-ray source	
Type	Gas-puff pinch
X-ray wavelength	9 - 14 Å
Spot diameter	1 mm or less
Input power	3 Hz 15 kw
X-ray intensity on wafer	10 mW/cm²

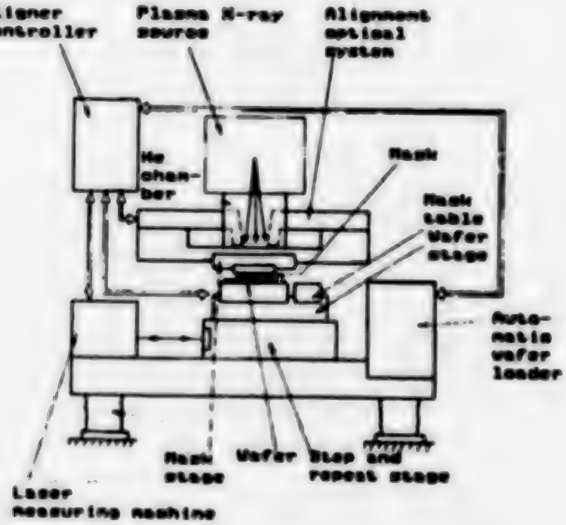


Figure 1. Schematic Figure of Aligner

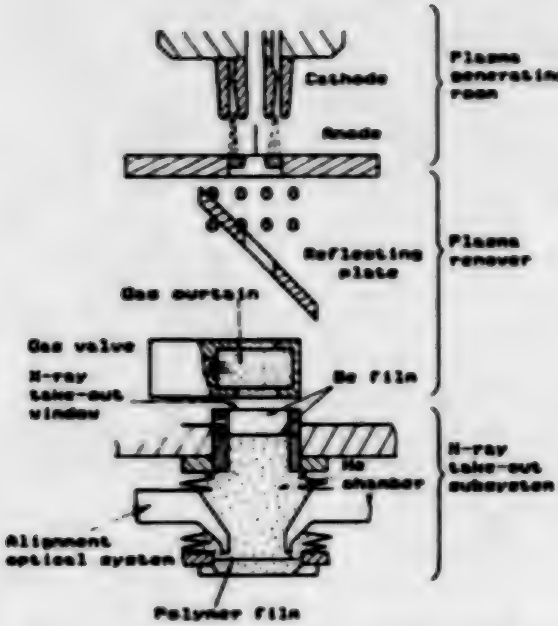


Figure 2. Structure of X-Ray Generating Room

side 10 times or more than before. As a result of such improvement, the maintenance interval could be 100 times or more longer than that for the conventional product.

With the X-ray take-out part, the He atmosphere provided between the Be window and the mask has improved the X-ray transmittivity 60 percent or more compared with that of the SR-1. Also, a polymer film of 1 μm thickness has been provided at the upper part of the mask to reduce mask replacement time by preventing air from mixing with He at the time of mask replacement.

In the evaluation by pattern transcription, a pattern of 0.3 μm width could be formed in a field 3 cm^2 by using FBM-G (sensitivity: 0 mJ/cm^2). The throughput is estimated at 20 sheets of 6-inch wafers/hr or more.

Since the plasma X-ray source emits comparatively larger power concentrated in a short pulse of 1 μs or less, it poses a problem of whether or not the heat absorbed in the mask can be effectively cooled and temperature rise can be suppressed. At present, little experimental data is available about this problem, so it is a subject for study in the future. According to NTT's report, the displacement of patterns at 6 mm intervals becomes about 0.05 μm or less and poses no serious problem.[9] However, this value corresponds to an expansion coefficient of about 8×10^{-6} (the temperature rise is estimated at about 3°C from the linear thermal expansion coefficient of silicon nitride film) and is not a small value for an 0.5 μm pattern. To secure the required superposition precision, the field size has to be limited and there is a fear of throughput drop.

The problem of mask temperature rise is also posed for the plasma X-ray source which performs pulse operation and the plasma focus X-ray source. To deal with this problem, actions such as lowering the power per shot, making repetition faster, and developing an effective mask cooling method will be necessary.

Figure 3 shows the principle of the alignment method of this device. This method is aimed at improvement of the dual diffraction grid method,[10] in which the positional discrepancy signal in the horizontal direction is too sensitive to changes in the gap between the mask and the wafer. This device detects as signal light I + 1 only specific-order diffracted lights which are diffracted in the direction of angle θ_H by making the diffraction grid pitch on the wafer twice as long as that on the mask. Alignment is performed by making the difference between I + 1 and the signal light I - 1 in the symmetric direction zero. This method greatly improves the gap dependency. To optimize alignment precision, however, a specific gap value has to be used. Also, since this beam source is a divergent one, a gap change causes a pattern position discrepancy error. Therefore, this device is separately provided with a single diffraction circuit on the mask to perform highly precise gap detection.

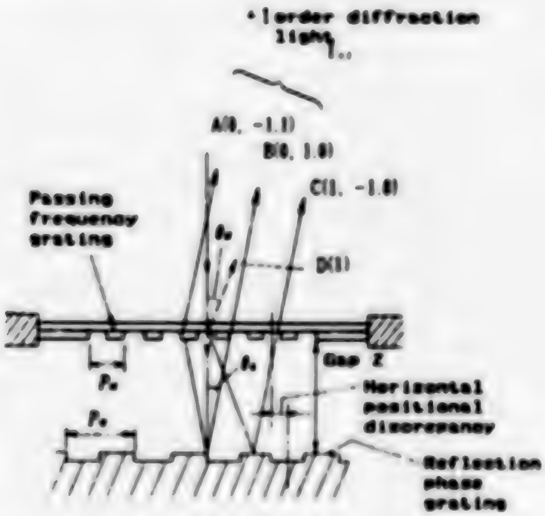


Figure 3. Principle of Horizontal Positional Discrepancy Detection by Double-Pitch Double-Diffraction Grating

2. Emissive Light Stepper XRS-200

Carl Jus A.G., of West Germany has introduced the vertical X-ray stepper XRS-200. This device is an enhanced version based on the MAX-1, device No 1, which has been installed on the BESSY emissive light beam line[12]; its main specifications are introduced in the handbook issued last year.[4] What is characteristic is adoption of a mechanism to scan the mask and wafer stage vertically. Since the beam shape of the emissive light is such that the width in the vertical direction is a few mm or less, the method of expanding the exposure area by scanning has to be determined. Methods

using the sway of the electron orbit of an accumulation ring and the vibration of a reflecting mirror have been tried, but each of these methods has its advantages and disadvantages.[13] The method adopted in this device, mechanical scanning of the mask and wafer, poses some problems, such as a complex mechanism, influence of the vibration that accompanies scanning, and difficulty in aligning control during exposure, but it is attractive in that no loss occurs in X-ray flux and no change is necessary for an accumulation ring or a beam line.

Figure 4 shows a tentative structure of an aligner/scanner unit.[11] The mask is mounted on a granite reference plate and the alignment mark is detected with an optical microscope from the beam source side. The alignment method is what has been conventionally reported,[14] whereby a positional discrepancy is indexed by processing the optical images of the marks on the mask and wafer, shown in Figure 5. The MAX-1 which adopts the same alignment method routinely yields alignment precision of 0.15 μm (3 σ) but no actual evaluation data has been reported on this device.

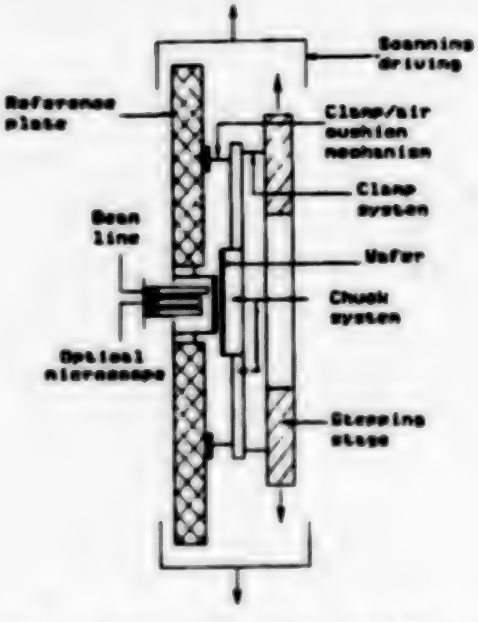


Figure 4. Aligner/Scanning Unit of X-Ray Stepper XRS-200

After prealignment, the mask and wafer are clamped to the reference plate and are finely aligned by the driving of a piezomotor. During exposure, the mask and wafer system unified with the reference plate is vertically scanned. Since the beam line, aligner part, and mask and wafer handler (automatic transfer and load mechanism) are physically separated from one another, no other parts exert vibration influence on the aligner part. The external dimensions of the stepper, including the frame are 1,000 mm wide x 1,855 mm deep x 2,250 mm high.

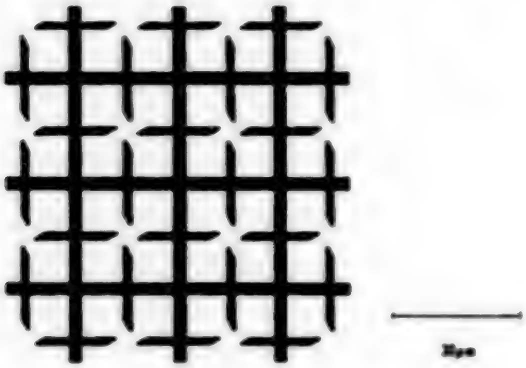


Figure 5. Alignment Marks of Superposed Mask and Wafer

Highly Bright X-Ray Source

As comparatively small-sized and highly bright X-ray sources, the development of various plasma X-ray sources is being put forward. These plasma X-ray sources are classified into gas-puff-type plasma X-ray source, laser plasma X-ray source, and plasma focus X-ray source. The characteristics and problems of these X-ray sources are introduced in detail in the handbook issued last year.[4]

The plasma X-ray source poses problems such as pulse operation of generally slow repetition, wear of electrode, scattering of debris, and large absorption of X-ray beams by the window, atmospheric gas, and mask-supporting films. Some of these problems can be dealt with as indicated in the previous section, and sufficient completion of the plasma X-ray source will have usefulness in the 0.3 to 0.5 μm pattern area. The transition radiation and the small-sized emissive light source are described below because a new attempt has been made to apply them to X-ray exposure.

1. Transition Radiation

Transition radiation is the phenomenon whereby X-rays are radiated when a high-energy electron crosses the boundary of two different materials. This phenomenon was clarified 20 or more years ago, but its use has been limited to detection of charged particles. Application of this phenomenon to lithography was reported at the SPIE Symposium in March 1987.[15]

X-rays are radiated in the shape of a cone, as shown in Figure 6, and the angular distribution is as shown in Figure 7. The angle θ and $\Delta\theta$ at which intensity becomes maximum in both cases is about m_0C^2/E (m_0C: stationary energy of electron; E: energy of electron). Since X-rays are radiated when electrons pass a thin film, a thin-film multilayer target is used to increase X-ray flux. The optimum thickness, number, and mutual distance of thin films is based on consideration of the generation efficiency and absorption of X-rays. Figure 7 shows a case wherein electrons of 54 MeV were radiated at a target of 18 sheets of 1-μm thick Be thin film, and

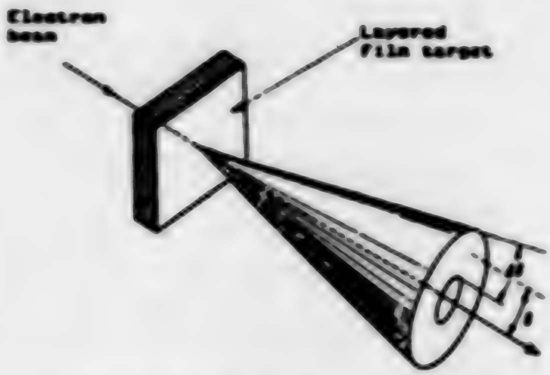


Figure 6. Cone-Shaped X-Ray Radiation by Transition Radiation

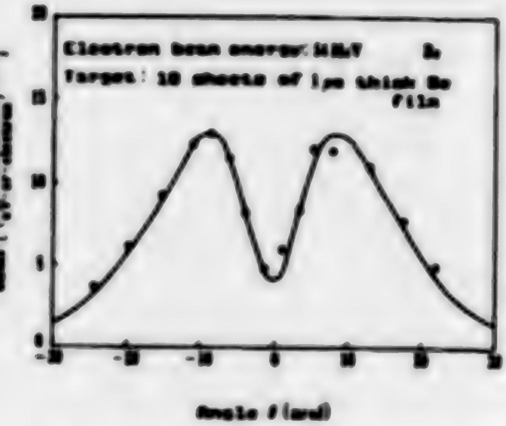


Figure 7. Measurement Results of Angular Distribution of Transition Radiation

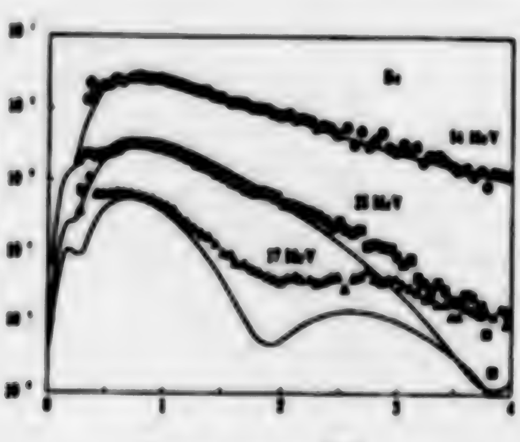


Figure 8. Energy Distribution of Photons Generated by Transition Radiation

Figure 8 shows the spectrum. If the target is replaced by Al, the X-rays whose energy is equal to or higher than the K absorption edge of Al (1.56 keV) are absorbed and a spectrum is obtained which has a peak near 1.2 keV and is suitable for lithography.

Pattern transcription was tested to the extent of obtaining preliminary experimental results. The brightness of transition radiation per electron is larger than that of emissive light by two or three positions, and the new experimental station under construction is thought to yield X-rays of 5 to 10 mW/cm^2 (the electron beam source is a 45 MeV lineac and the current is some several tens of μA). Transition radiation is superior to the plasma X-ray source in spectrum, controllability, directivity, and cleanness, and its development hereafter is to be expected.

2. Small-Sized Emissive Light Source

The emissive light is two positions or more larger in intensity than the electron-beam-exciting-type X-ray source. Also, its directivity is sufficient to make half-shade blur and runout error negligible. Therefore, emissive light exposure is superior in resolvability, line-width controllability, and superposition precision, and throughput is expected to be sufficiently high. At present only the emissive light source is capable of pattern transcription of a range of 0.25 μm to about 0.1 μm with a single layer resist of high applicability to minute patterns.

For practical use of emissive light exposure, development of a small-sized low-priced electron accumulation ring is important. Table 2 shows the parameters of the main small-sized accumulation rings in developmental or planning stages at present. NTT and Soltech Corp. are putting plans forward but no details are available.

The COSY is the leading development of a small-sized ring which uses a superconductive electromagnet for deflection of electron orbits. In the initial plan, a circular ring was aimed at,[16] but this has been changed to an arena-shaped ring which introduced straight line parts. The COSY was successful in an electron incident test with an ordinarily conductive magnet in April 1986, a superconductive magnet was installed in April 1987, and the COSY was said to be scheduled to enter a trial run by fall 1987.[17] However, the company seems to be behind schedule.

Sumitomo Heavy Industries' plan is a challenging one in that it is aimed at realization of the superconductive circular ring which the COSY abandoned, using the newly developed one-half resonant incidence method.[18] This plan contains new ideas to reduce the influence of the gas discharged from the vacuum vessel wall by emissive light radiation and for the RF cavity structure. The company made public an outline of the development at the three-beam symposium held in California in May 1987. According to the outline, the company is manufacturing a trial device and will complete the device in 1988.

Table 2. Main Parameters of Small-Sized Rings in Developmental or Planning Stages

Developing organization	IFT[1]	Sumitomo Heavy Industries	Sumitomo Electric Industries[2]	NEYRPIC
Ring name	COSY		NIJI-II	MARS
Accumulated electron energy E (GeV)	0.59	0.65	0.615	0.8
Accumulated current I (mA)	300	300	200	>100
Deflecting magnet type	Superconductive	Superconductive	Superconductive	Ordinarily conductive
Deflecting magnetic field strength B (T)	4.5	4.34	4.1	1.67
Radius of curvature of electron orbit R (m)	0.44	0.5	0.5	1.6
Peak wavelength[3] λ_p (A)	5.0	4.3	5.1	7.3
Incident energy Ei (MeV)	50 (M)[4]	150 (L)[5]		10 (M)[4]
Number of deflecting magnets	2	1		4
External dimensions (m)	2 x 6	3ϕ	3ϕ	5ϕ

Notes:

1. Fraunhofer-Institut für Festkorpertechnologie. According to the COSY-MicroTec Corporation's technical material, which is for putting COSY on the market, E = 0.63 GeV, but calculation from the values of R and λ_p leads to E = 0.59 GeV.
2. Practial use of the technique which Electrotechnical Laboratory has developed at the request of Research Development Corp. of Japan is aimed at.
3. $\lambda_p = 2.35\ R/E^3$.
4. Incidence by microtron.
5. Incidence by linear accelerator.

The project of Sumitomo Electronic Industries, Ltd., entrusted by Research Development Corp. of Japan will be aimed at practical use of the undulation ring developed by Electrotechnical Laboratory.[19,20]

With the superconductive ring, the electron orbit radius itself can be made about 50 cm, but the yoke requires a large quantity of iron (120 tons for Sumitomo Heavy Industries' ring) to reduce leakage flux and a strong electromagnetic force which acts between coils. Therefore, the external dimensions become quite large (Table 2). On the other hand, the yoke has the advantage of being effective for shielding of emissive beams.

To make the whole emissive light source smaller, the electron incident device also has to be made smaller. The microtron is compact, but few actual results of its use are available in this country. With the linear accelerator, energy is proportional to the acceleration length. Energy of 150 MeV seems to be obtainable per 10 m.[19] In any case, after incidence at a low energy level, electrons are to be accelerated to the final accumulated energy by a synchrotron. In low energy incidence, the short life of the electron poses a problem. Electrons incident upon a ring are partly lost by the Touscheck effect (scattering and loss of electrons by the Coulomb mutual action among electrons in a bunch) and by collision with remaining gas molecules,[21] and these losses are more remarkable for lower energy. Therefore, the life of electrons must be sufficiently long, in relation to the time necessary for multiple times of incidence and the acceleration that follows, to reach the needed current. The superconductive type is incapable of a rapid rise in the magnetic field and is thought to need several minutes for acceleration by a synchrotron.[19,20] Experiments with the Electrotechnical Laboratory's test ring NIJI-I (ordinarily conductive type), which is used to investigate the problem of low-energy incidence, succeeded in accumulation of 160 mA at 160 MeV and showed that incidence at 150 MeV or more poses few problems.[20]

The life of the current at the finally accumulated energy is also important from the viewpoint of practical use. Recently, a technique was reported to allow separate evaluation of the contributions by the remaining gas, discharged gas and the Touschek effect to the attenuation of accumulated current. According to this report, the Touschek life is considerably longer than that which is conventionally forecast.[19,20] Enhancement of vacuum and an appropriate measure for discharged gas seem to realize a current life of several tens of hours.

The parameters of the accumulation ring to satisfy the required performance of lithography are investigated next. To obtain throughput of about 50 sheets of 6-inch wafers/hr in an exposure field of 2.5 x 2.5 cm, the exposure time for each field has to be about 1 s. The relationship between the product EI of the electron energy and the current of the accumulation ring which satisfies the above condition and the peak wavelength λ_p of the emissive light spectrum becomes as shown in Figure 9 from the power absorbed by the resist.[22] The illustration shows the relationship between E and λ_p at the same time. In this illustration, the absorption characteristic of the resist is assumed to be the same as that of PMMA, and energy that corresponds to one-tenth of the sensitivity of PMMA[23] (120 J/cm^3) is assumed to be absorbed by the resist at a depth 1 μm from the surface.

On the basis of the relationship shown in Figure 9, the relationship among resist sensitivity, wavelength (λ_p), and throughput (exposure time) and parameters (E, I, B, and R) of the accumulation ring can be evaluated. When B = 1.67 T, for example, accumulated current of about 140 mA is found to be necessary to expose in 1 s a resist which is 10 times as sensitive as PMMA through a 20-μm thick Be film or a 2-μm thick BN film if E = 1.0 GeV.

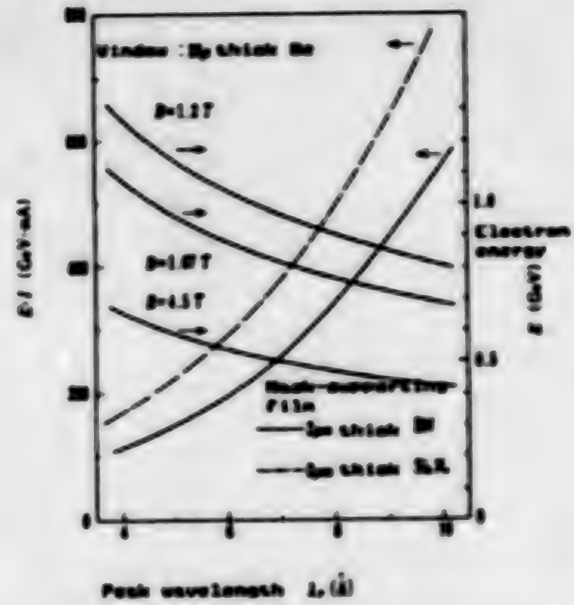


Figure 9. Parameters of Accumulation Ring Necessary To Expose in 1 s a Resist Which Is 10 Times as Sensitive as PMMA
(E - accumulated electron energy, I - accumulated current, and B - deflecting magnetic field)

To expose an area of 2.5 x 2.5 cm uniformly, however, emissive light has to scan vertically, and current has to be increased (three times) by the corresponding amount or a highly sensitive resist has to be used. If B is made larger by using a superconductive deflection electromagnet, E becomes lower as compared with the ordinarily conductive type of the same λ_p, and larger current becomes necessary to obtain the same power.

High-Precision Alignment Technique

For practical use of X-ray exposure, a high-precision alignment technique that corresponds to minute pattern dimensions is required. In addition to the company in West Germany and NTT, IBM,[24] Toshiba Corp.,[25] and Electrotechnical Laboratory[26] each has developed a new method. The methods of the West German company and IBM utilize detection of the optical images of superposition marks, but each of the other methods uses diffraction gratings.

Figure 10 shows the principle of the Electrotechnical Laboratory's method. In this method, three diffraction gratings are symmetrically arranged, and the influence of a change in the gap between the mask and the wafer is prevented from entering into signal light by making the period of wafer grating 1.5 times as large as that of the mask grating. Furthermore, this method uses as the light source the horizontal Zehman laser which contains two frequency components whose planes of polarization are perpendicular to each other and which detects positional discrepancy from the phase

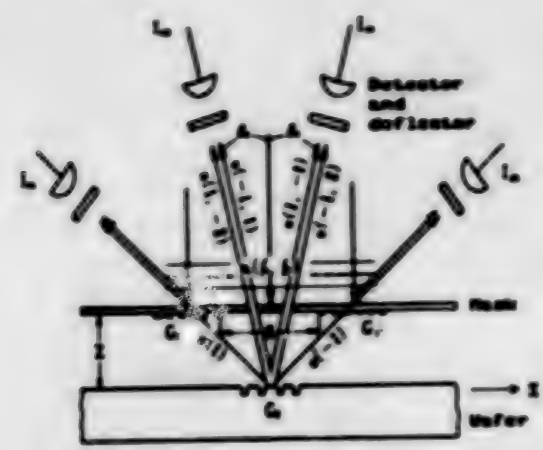


Figure 10. Principle of Optical-Heterodyne Positional-Discrepancy Detection Method Which Uses Three-Diffraction Gratings

difference of the two beat signals I_{S_1} and I_{S_2} which are detected. Electrotechnical Laboratory has confirmed that this method allows positioning control at a precision within 0.01 µm. This method is capable of high-precision positioning without influence of a gap change and is strong against changes in signal light intensity and noises. Therefore, it is thought to be of high practical usability.

If transcription of 0.25 µm patterns is the aim, the most realistic selection will be emissive light lithography which can realize basic advantages of X-ray exposure. However, practical use of lithography is not necessarily easy. The main problems unique to X-ray lithography or emissive light lithography are establishment of a mask technique and development of a small-sized ring, but common problems which are unavoidable when 0.25 µm is the aim have to be resolved.

Since X-ray lithography is for equal-sized transcription, the requirement for a mask is strong and is considered one of the key points for practical use. The reduced projection method based on a reflective optical system is also in trial stages. At the present state, however, a wavelength of considerable length has to be used. Therefore, a mask and resist suitable for the long wavelength has to be put forward at the same time.

Emissive light is certainly strong compared with other X-ray sources, but it has disadvantages such as attenuation at the window and mask-supporting film, a drop in intensity with expansion of the exposure area, and it is not sufficiently strong to leave a margin. If the problems that accompany low-energy incidence and a drop in the life of the accumulated current caused by gas discharge that occurs with emissive light radiation are taken into consideration, the smaller the accumulated current, the better. To make accumulated current smaller, the use efficiency of emission power and resist sensitivity must be enhanced. A superconductive small-sized ring requires current larger than that of an ordinarily conductive type, and to

what degree this current can be made possible with low-energy incidence is a subject for wide study.

The demand for a small-sized emissive light source is strong and is thought of as an important condition for practical use. At the present state, the ordinarily conductive type is thought of as a safer selection, but if a smaller emissive light source is realized so as to satisfy the requirement with development of the COSY and other small-sized rings, the light source will greatly advance the practical use of emissive light lithography.

Footnotes

1. V. Pol, et al., PROC. SPIE, Vol 633 No 6, 1986.

2. Sato, et al., Papers for 47th Meeting of Japan Society of Applied Physics, 1986, p 324.

3. Horiike, et al., NIKKEI MICRODEVICE, February 1986 issue, p 63.

4. Suzuki, "Super LSI Manufacturing and Testing Devices Handbook," 1987 version, 1986, p 115.

5. T. Hayasaka, et al., Proc. 10th Symp. Electron Ion Beam Sci. Tech., Electrochem. Soc., Pennington, 1982, p 347.

6. H. Kinoshita, et al., J. VAC. SCI. TECHNOL., Vol B1, 1983, p 1276.

7. I. Okada, et al., Ibid., Vol B4, 1986, p 243.

8. A. Une, et al., Proc. SPIE, Vol 773, 1987, p 45.

9. H. Yoshihara, et al., Ibid., Vol 632, 1986, p 133.

10. D.C. Flanders, et al., APPL. PHYS. LETT., Vol 31, 1977, p 426.

11. E. Cullman, et al., Proc. SPIE, Vol 773, 1987, p 2

12. A. Heuberger, MICROELECTRON. ENG., Vol 5, 1986, p 3.

13. Atoda and Ito, "Shingaku Giho," Technical Report of Japan Society of Communication, SSD85-103, 1986.

14. G. Doemens, et al., Siemens Forsch. und Entwickl.-Ber., Vol 13, 1984, p 43.

15. M.A. Piestrup, et al., Proc. SPIE, Vol 73, 1987, p 37.

16. A. Heuberger, Proc. SPIE, Vol 448, 1983, p 8.

17. H. Betz, Extended abstracts of the 18th (1986 International) Conference on Solid-State Devices and Materials, Japan Society Appl. Physics, 1986, p 5.

18. Takahasi, Material of Ninth Study Meeting, Subcommittee B, 145th Committee, Japan Society for the Promotion of Science, 1986, p 17.

19. Tomimasu, SHINKU, Vol 29, 1986, p 299.

20. Ibid., Material of Ninth Study Meeting, Subcommittee B, 145th Committee, Japan Society for the Promotion of Science, 1986, p 1.

21. E.M. Rowe, "Synchrotron Radiation," edited by C. Kunz (Springer-Verlag), 1979, Chapter 2.

22. N. Atoda, and K. Hoh, Proc. Intern. Symp. VLSI Technology, Systems and Applications, Taipei, 1987, p 48.

23. R.P. Haelbich, et al., J. VAC. SCI. & TECHNOL., Vol B1, 1983, p 1262.

24. N. Bobroff, et al., Ibid., Vol B4, 1986, p 285.

25. Ishibashi, et al., Papers of the Spring General Meeting of the Precision Engineering Association, 1987, p 769.

26. J. Itoh, et al., Proc. SPIE, Vol 773, 1987, p 7.

20111/9365

Focused Ion Beam Devices Developed

43065053 Tokyo DENSHI ZAIRYO BESSATSU in Japanese Nov 87 pp 99-104

[Article by Hiroaki Morimoto, Beam Application Technology Group, LSI Laboratory, Mitsubishi Electric Corporation]

[Excerpts] The focused ion beam (FIB) is an ion beam focused to a diameter of around 0.1 μm. It is a very promising technology--it can even be called one of the ultimate semiconductor element manufacturing technologies--because it can carry out etching, depositing, ion implantation, and photoresist exposure, all with lithography.

The development of ion sources using liquid metals[1,2] started the research on FIB technology. The focusing of an ion beam to a diameter of only about 0.1 μm was made possible by the small ion source size and high luminance. The first FIB equipment using a liquid metal ion source was announced by Hughes in 1979.[3] Later, researchers began studying FIB applications to etching, deposition, ion implantation, resist exposure, etc., and technology has recently reached a level enabling fabrication of many devices.[4-6]

High throughput is a very important factor for applications as manufacturing technology. FIB, like electron beam lithography, is lithographic technology and requires an irradiation level several digits larger depending on applications. This is considered to have been a major stumbling block to practical use of the technology.

Repairing and evaluation processes are promising areas where FIB technology application is possible in the near future because the processing area is extremely small and throughput poses no major problem. Typical applications include the repair of photomask defects.[7] Large-scale integration (LSI) wiring processing for evaluation is also nearing a level allowing practical use.[8] FIB's application to secondary ion mass spectrometers (SIMS) in the submicron region, which has been impossible, is expected to have big merits.[9]

General-Purpose FIB Equipment

A considerable amount of FIB equipment for R&D use is sold by Japanese and foreign makers. Such equipment can be broadly classified as the ion beam

lens barrel, specimen quality, control system, and power source system. The ion beam lens barrel consists of the ion source, mass separator, electrostatic lens and beam deflector. Specifications of general-purpose FIB equipment currently available on the market are provided in Table 1. Ion sources and mass separators are omitted because all of them use the liquid metal ion source and the EXB separator.

Table 1. Specifications of General-Purpose FIB Systems Available on the Market

Model name	EIP-100A	Micro Focus	JIBL-100A	JIBL-106S	JIBL-150	NanoFab-150	IBL-100S
Maker	Elionix	IBS (U.S.)	JEOL, Ltd.			MBI (U.S.)	VG (U.K.)
Sold in Japan by	*	Marubeni High-Tech	*			Undecided	Undecided
Maximum acceleration voltage (kV)	100	150	100	100	150	150	100
Minimum beam diameter (μm)	0.1	0.1	≤0.1	≤0.1	≤0.1	0.05~0.1	0.05
Beam current density (A/cm²)	1	1	1	1	1	≥5	5
Mass separation resolving power	30	50	≥20	≥20	≥20	≥20	20
Lithographic field size	2-300μm² Continuously variable	128μm²	400μm² 960μm² Switchable	1mm²	1mm²	1mm² (25kV) 100μm² (150kV)	1mm²
Computer control	Optional	PDP11/24	Optional	PDP11/84	VAX11/730 HP9920	Available	PDP11/24
Maximum specimen size	4"	6"	6"	6"	4"	6"	4"
Laser interferometer	Not available	Available	Not available	Available	Available	Available	Available
Others			Ultrahigh vacuum specimen chamber			SIM function possible	Ultrahigh vacuum specimen chamber

General-purpose models can be broken down broadly as those with a maximum acceleration voltage of 100 kV and those with 150 kV, models with a laser interferometer and those without, and models whose specimen chamber is an ultrahigh vacuum and those whose specimen chambers are not.

The minimum beam diameter and beam current density shown in the table are values provided in the specifications. It is not clear if they are design values, target values or actually measured values. Even if they are claimed to be actually measured values, it should be noted that no means has yet been established to accurately measure an ion beam diameter.

1. EIP-100A (Elionix)

This is FIB equipment with a maximum acceleration voltage of 100 kV, mass separating and resolving power of 30, and a variable lithography field size of 2 to 300 μm. A computer control function is available as an option.

2. Micro Focus (IBS)

Micro Focus has a maximum acceleration voltage of 150 kV, mass resolving power of 50, and a lithographic field size of 128 μm. It is equipped with

a 6 inch specimen chamber with a laser interferometer. IBS also produces Micro Trim designed exclusively for mask repairing.

3. JIBL-100A, JIBL-106S, JIBL-150 (JEOL, Ltd.)

JEOL, Ltd., manufactures the JIBL-100 with an acceleration voltage of 100 kV and the JIBL-100A with an ultrahigh vacuum specimen chamber. The resolving power of mass separation is 20. The maximum lithographic field size is 400 μm at a work distance of 19 mm and 960 μm at 39 mm.

The JIBL-106S has the same ion beam lens barrel as that of the JIBL-100A, but it also has a 6 inch specimen chamber with a laser interferometer and lithography capability similar to that of an electron beam lithographic system.

The JIBL-150, equipped with a 4 inch specimen chamber with a laser interferometer, has a maximum acceleration voltage of 150 kV.[10] The system is controlled by the HP9920. The VAX 11/730 serves as an interface with the operator and carries out lithographic data conversion and pattern lithography.

The company has developed the JIBL-200S with a maximum acceleration voltage of 200 kV. It has a function that automatically switches the electrostatic lens to the acceleration mode when the acceleration voltage is low in order to prevent an increase in the beam diameter resulting from a rise in chromatic aberration.[11]

4. Nano Fab-150 (Micro Beam)

The development of this equipment is still underway. It will achieve a wide range of acceleration voltage by accelerating and decelerating the ion beam with the objective lens ((Einchel) lens). Asymmetric lenses will be used for the first stage lenses to reduce aberration. It will be able to analyze secondary ions generated from the specimen for end-point detection of SIMS and processing.

5. IBL-100S (VG)

The IBL-100S, FIB equipment made by VG, is marked by a superhigh vacuum specimen chamber and a specimen table with a laser interferometer. A VG-developed pulse motor that operates in a superhigh vacuum is used to drive the specimen table.

FIB Equipment for Repairing

FIB technology is expected to be put to practical use first for repairing LSI circuit patterns. The introduction of the technology will result in qualitative and cost improvements particularly in repairs of photomask defects. Figure 2 shows a photomask repairing method using the FIB. Black defects and white defects are repaired by sputter-etching and ion beam-assisted deposition, respectively. The merits of the use of the FIB include the following:

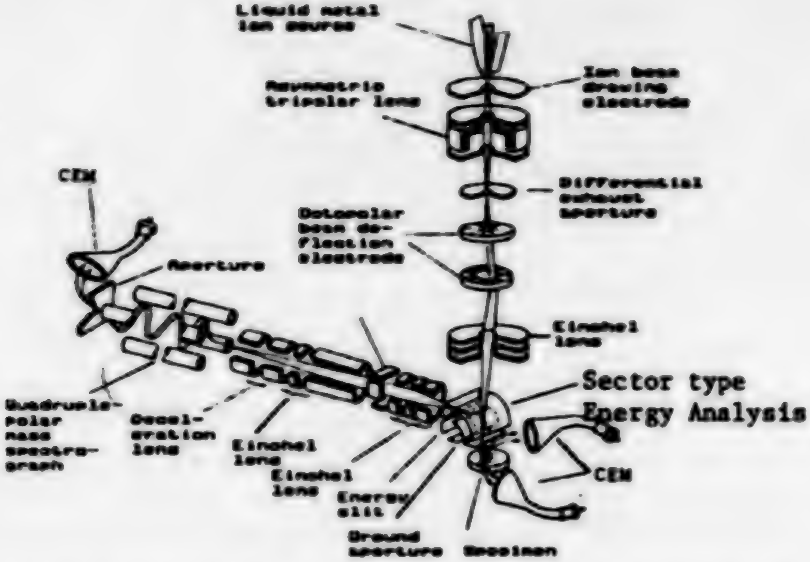
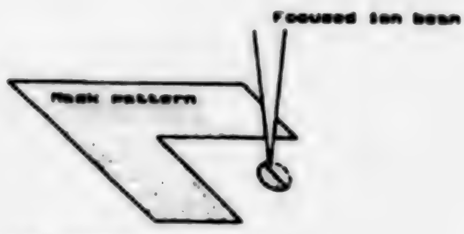
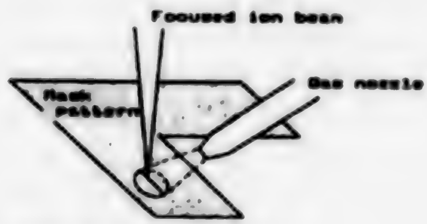


Figure 1. Ion Optical System of Micro Beam-Made NanoFab-150



(a) Black defect repair



(b) White defect repair

Figure 2. Photomask Repair Using FIB

(1) White defects can be repaired in a shorter process.

(2) Highly accurate ion beam positioning (≈0.1 μm) allows high precision repairs.

(3) The lithographic function allows repairing of deformed patterns.

The ion beam irradiation damages the glass substrate and reduces the light transmission rate particularly in sections where black defects have been repaired, affecting transfers to wafers. But modification of processes after repairs and repairing equipment is likely to solve this problem.

Attempts have been made to apply the technology to repairing LSI chip circuits. These attempts are designed to use maskless high-precision etching and metallic film deposition for analysis and repairing of LSI defects.

Table 2 shows published specifications of mask repairing equipment available on the market. As is the case with general-purpose FIB equipment, it is not clear if the beam diameter, ion source life, and repairing accuracy are design targets or actual values. These systems are all equipped with an interface with mask defect inspection equipment (network, magnetic card, etc.) and a neutralizing electron gun to prevent the mask substrate's charge-up. The speeds for black point repairing are values for 0.1-μm chromium masks.

Table 2. Specifications of Photomask Repairing Equipment Available on the Market

Model name		MicroTrim	NanoFix-50	KLA-Micrion 808	SIR-1000
Maker		IBS	Micro Beam	Mirion	Seiko Instruments
Sold in Japan by		Marubeni High-Tech	Undecided	Tokyo Electron	" "
Maximum acceleration voltage(kV)		50	50	25	20
Ion source		Ga	Au-Si	Ga	Ga
Minimum beam diameter (μm)		0.1	0.2	0.2	?
Repairing area		7"	?	7"	7"
White defect repairing		Carbon deposition	Carbon deposition	Optical structure or carbon deposition	Carbon deposition
Repairing accuracy (μm)		0.1	?	0.1	0.25
Repairing speed (μm^2/min)	Black defect	16	40	20	4
	White defect	16	20	Optical structure: 4 Carbon deposition: 30	6

1. **MicroTrim (IBS)**[12]

The ion beam lens barrel, with a maximum acceleration voltage of 50 kV, consists of a two-stage lens system. The barrel is made by IBS (formerly known as Dubilier). The minimum beam diameter is 0.1 μm. White defect repairing is done by carbon deposition. Repairing accuracy is 0.1 μm. The maker seems to be studying reducing damage on the glass substrate by ion beam irradiation with some improvements in the defect repairing process, but details are not disclosed. Because of a high signal-to-noise ratio, secondary ions are detected for end point detection of mask pattern imaging and etching.

2. **NanoFix-50 (Micro Beam)**

The NanoFix-50 is marked by the use of a gold-silicon (Au-Si) alloy liquid metal ion source for observation and positioning with an Si ion beam and repairs with an Au ion beam. As the mass of Si is relatively small, damage on the glass substrate can be reduced. Conversely, Au has large mass and a high sputtering rate, enabling high-speed repairs. Ion beam switching is done by EXB type mass separating equipment, which automatically corrects a beam position shift at the time of switching. Secondary ions are used for end point detection during sputter-etching (utilizing a difference between Cr and Si). Ion beam-assisted deposition is used to make Cr film to repair white point defects. The ion beam's maximum acceleration voltage is 50 kV. The system is now under development for completion in December 1987.

3. **KLA/Micrion 808 (Micrion)**

The ion beam's maximum acceleration voltage is 25 kV. Two methods are available for white defect repair: the optical structure method, under which light is shielded by turning the mask surface prism-like with ion beam etching, and carbon deposition. To reduce damage on the substrate by the ion beam during mask pattern imaging, a charge neutralizing method has been improved to detect high-yield secondary electrons (this is called "multiplex imaging"). The maker announced a new model, 818, which has the Auto Clone-It function that automatically repairs pattern deforms based on information on the pattern of an adjacent similar chip.

4. **SIR-1000 (Seiko Instruments and Electronics, Ltd.)**[13]

Seiko Instruments and Electronics, Ltd., is the only Japanese maker of FIB mask repair equipment. The feature of the SIR-1000 is that secondary ions are detected to analyze Si and Cr in order to detect the end point of etching. When Cr still remains, it can be detected in secondary ions, but when it no longer remains, Si from the glass substrate will be detected, allowing the determination of the end of etching. As there are some irregularities in Cr film thickness and etching rates, the detection of the end point of etching is considered necessary from the viewpoint of preventing unnecessary damage on the glass substrate.

5. **SMI-8100 (Seiko Instruments and Electronics)[14]**

This equipment is slightly different from the other mask repair systems so far introduced in that it is designed for LSI circuit modification. Before measurement with an electron beam tester, a hole is made in the passivation film to facilitate measurement.[15] It is possible to cut a desired circuit, connect a circuit with metallic film deposition, and make a hole in the insulating film to expose the lower layer wiring pattern and then draw the wiring out by depositing a metallic film. The maskless FIB processing is simple and is applicable to packaged LSIs. Processing of LSIs allows operation and defect analyses at a high level that has so far been unavailable.[16] It is also considered to be effective in repairing defects stemming from fuse cutoff and connection.

The equipment's maximum acceleration voltage is 50 kV, minimum beam diameter is 0.1 μm or smaller, minimum processing precision is 0.3 μm or less and maximum specimen size is 4 inches. It uses gallium ions. The selective deposition of tungsten (W) is used for forming the wiring by resolving $W(CO)_6$ gas with the irradiation of an ion beam.

FIB technology is expected to be put to practical use first for photomask defect repairs and FIB equipment will be introduced rapidly. LSI pattern repairing with the technology will also become available in the near future. Maskless processing is expected to remain in the R&D phase for the time being. But interest in this area is rising, as evidenced by increasing announcements of research results at academic meetings.

Footnotes

1. V.E. Krohn & G.R. Ringo, "Ion Source of High Brightness Using Liquid Metal," APPL. PHYS. LETT., Vol 27 No 9, 1975, p 479.

2. R. Clampitt, K.L. Aitken, and D.K. Jefferies, "Intense Field-Emission Ion Source of Liquid Metals," J. VAC. SCI. TECHNOL., Vol 12 No 6, 1975, p 1204.

3. R.L. Seliger, J.W. Ward, V. Wang, and R.L. Kubena, "A High Intensity Scanning Ion Probe With Submicrometer Spot Size," APPL. PHYS. LETT., Vol 34 No 5, 1979, p 310.

4. S. Shukuri, Y. Wada, H. Masuda, T. Ishitani, and M. Tamura, "Submicron Channel MOSFET Using Focused Boron Ion Beam Implantation Into Silicon," JPN. J. APPL. PHYS., Vol 23 No 8, 1984, p L599.

5. R. Reuss, D. Morgan, E.W. Greeneich, W.M. Clark, Jr., and D.B. Rensh, "Vertical upn Transistors by Maskless Ion Implantation," J. VAC. SCI. TECHNOL., Vol B3 No 1, 1985, p 62.

6. Y. Sasaki, H. Morimoto, H. Onoda, M. Komaru, M. Kobiki, Y. Mitsui, O. Ishihara, and T. Kato, "Low Noise GaAs MESFETs Fabricated by Focused Ion Beam Lithography," INST. PHYS. CONF. SER., Vol 79 No 9, 1986, p 487.

7. A. Wagner, "Applications of Focused Ion Beams to Microlithography," SOLID STATE TECHNOL., May 97 (1983) [as published].

8. L.R. Harriott, A. Wagner, and F. Fritz, "Integrated Circuit Repair Using Focused Ion Beam Milling, J. VAC. SCI. TECHNOL., Vol B4 No 1, 1986, p 181.

9. R. Levi-Setti, G. Crow, and Y.L. Wang, "Progress in High Resolution Scanning Ion Microscopy and Secondary Ion Mass Spectrometry Imaging Microanalysis," SCANNING ELECTRON MICROSCOPY, No 11, 1985, p 535.

10. H. Sawaragi, T. Osafune, R. Aihara, S. Matsui, and K. Mori, "Focused Ion Beam Lithography System (JIBL-150)," Proceedings of the 17th Symposium on Ion Implantation and Submicron Fabrication, The Institute of Physical and Chemical Research, 196, p 141.

11. R. Aihara, H. Sawaragi, H. Morimoto, K. Hosono, Y. Sasaki, and T. Kato, "Performance of a 20-200 kV Focused-Ion-Beam System With a New Optical Design Concept," to be published in J. VAC. SCI. TECHNOL., Vol B5 No 6, 1987.

12. H.C. Kaufmann, W.B. Thompson, and G.J. Dunn, "FIB Mask Repair With MicroTrim," Proceedings of SPIE, Vol 632, Electron-Beam X-Ray, and Ion-Beam Techniques for Submicrometer Lithographies V, 1986, p 60.

13. M. Yamamoto, M. Sato, H. Kyogoku, K. Aita, Y. Nakagawa, A. Yasaka, R. Takasawa, and O. Hattori, Ibid., 1986, p 97.

14. Minafuji and Adachi, "FIB (Focused Ion Beam) Processing Technology," JOURNAL OF PRECISION ENGINEERING SOCIETY, Vol 53 No 6, 1986, p 15.

15. H. Arima, T. Matsukawa, J. Mitsuhashi, H. Morimoto, and H. Nakata, "Electron Beam Testing of VLSI Circuits Assisted by Focused Ion Beam Etching," MICROELECTRONIC ENGINEERING, Vol 4 No 2, 1986, p 107.

16. Y. Mashiko, H-Morimoto, H. Koyama, S. Kawazu, T. Kaitoh, and T. Adachi, "A New VLSI Diagnosis Technique: Focused Ion Beam Assisted Multi-Level Circuit Probing," presented at the 25th International Reliability Physics Symposium, April 1987.

20159/9365

Development, Operation of Clean Rooms Described

43065055 Tokyo DENSHI ZAIRYO BESSATSU in Japanese Nov 87 pp 159-164

[Article by Koki Hashimoto, chief, Technical Division, Takasago Thermal Engineering Co., Ltd.]

[Text] **Clean Room Technology Trends**

The semiconductor business has, at last, started picking up after its long depression, and the tendency toward equipment investment is becoming stronger. However, Japan's semiconductor industries are suffering from the restrictions caused by the semiconductor friction between Japan and the United States and the remarkable progress of the semiconductor industries in Korea and Taiwan, accompanied by the strong yen. With such a background, Japanese semiconductor manufacturers are fiercely competing with one another, placing still more emphasis on the technical development for the age of the 16K bit RAM. With the development of semiconductor elements, the clean room requirement is becoming more severe. However, it is believed that few problems exist involving air cleanliness and the efficiency of the HEPA and ULPA filters, since they have reached the limits of recent clean room technology through the accumulation of actual results. Many issues are discussed regarding the management and operation of the clean room, such as how to make the air flow and countermeasures against magnetism and static electricity, and how to clean the interior of the clean room and the manufacturing device. Since these are significant factors when determining the faults of a device, the accumulation of careful findings is required to solve these problems. Although these management problems do not involve the clean room technology itself, they are closely connected with the specifications and the shape of the clean room, which must be thoroughly examined during the design process. In this respect, the recent clean room technology has required an overall knowledge not only of the air cleanliness, temperature and humidity, but also of the semiconductor manufacturing device, its functions and characteristics, and various utilities. It can be said that the semiconductor environment and the clean room consist of a close connection among all these factors.

1. Air Cleanliness and Measuring Technology

In the semiconductor plants in Japan, super clean rooms of 0.1 μm, class 1, 10, etc., have been established. On the other hand, the amount of dust of

0.5 μm per cubic foot is less than that found in class 1, the highest air cleanliness classification described in the revision of the U.S. Federal Standard 209B, while the number of dust particles of 0.1 μm is 35. That is, according to the authoritative revised U.S. Federal Standard 209B (209C in the future), this value (0.1 μm, class 35) has been assigned as the standard for the highest level of cleanliness. This is due to such academic reasons as limits in the performance of the existing measuring instruments and the many errors that are found in the measured value if the number of particles is too small. Table 1 compares the views of Japan and the U.S. Federal Standard 209B revision toward classes 1 and 10. It is believed that the expression of the 0.1 μm class 1 will also be used in the future in the clean rooms of semiconductor plants in Japan, since the pursuit of ultimate high cleanliness through these technical standards is recognized as valid. The reliability of the measured results will probably be raised for the laser particle counter, appearing in the market as a high-precision particle counter that can absorb 1 cubic foot of air per minute, making a particle of 0.1 μm the target. A more practical method for counting the number of particles adhering to the wafer is being studied as a method of measuring air cleanliness.

Table 1. Comparison of Methods Expressing Class of Cleanliness

		Amount of dust in air (particles/ft^3)	
	Size of dust(μm)	Proposed revision of U.S. Federal Standard 209B	Superclean room in Japanese semiconductor plant
Class 1	≥ 0.5	Fewer than 10	Generally it is determined
	≥ 0.3	" " 3	with reference to particle
	≥ 0.2	" " 7.5	size distribution of the U.S. Federal Standard
	≥ 0.1	" " 35	Under 1
Class 10	≥ 0.5	" " 10	It is determined in the same
	≥ 0.3	" " 30	way as for Class 1
	≥ 0.2	" " 75	
	≥ 0.1	" " 350	Fewer than 10

2. Shape of Clean Room

It is believed that the down-flow-type clean room (Figure 1), the most popular currently, will remain for some time. High LST integration and the development of higher performance manufacturing devices will occur at the same time. Therefore, the trend is to give priority to the flexibility of the clean room that can exchange/install whatever manufacturing device might be developed. The down-flow-type has the advantage of flexibility because the same high level of cleanliness can be obtained at any place in

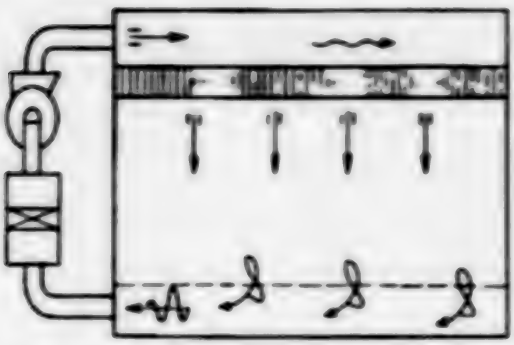


Figure 1. Down-Flow-Type Clean Room

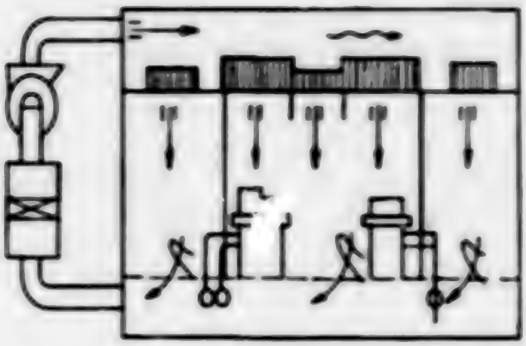


Figure 2. Energy-Saving-Type Down-Flow Clean Room

the room. On the other hand, the weakness of the down-flow-type has been the amount of power needed to operate it, but recently an energy-saving down-flow-type, that can freely distribute the laminar flow and the turbulent flow based on the down flow to cover up this weakness (Figure 2) has been gaining popularity. The ULPA filter, whose collection efficiency is higher than that of the HEPA filter, is domestically produced and is being used for the super clean room. The fact that the fine processing of 4M and 16M bits in clean air, using a combination of the ULPA filter and the down-flow, has been successful is a great help in determining the course of development of these clean rooms, even though it is only at the stage of test manufacture and research.

3. Investment Efficiency of Clean Room

The price competition in the semiconductor industry can be termed severe. The manufacturers must tackle cost reduction in order to survive, but the power cost for operating the clean room is a great factor in the overall cost. If a relaxation in the price competition cannot be expected, adopting energy-saving measures for clean room operation must be viewed as a more important subject. It is very difficult for the required performance of the semiconductor plant's clean room and energy saving measures to be made to coexist. However, one cannot help but tackle this problem with indomitable resolve in such circumstances. For this purpose, clean room designers must think from the beginning, throwing away preconceived concepts. In addition, the engineers employed at the semiconductor plants must be willing to examine fresh proposals, differing from the past methods and ideas, and throw away the preconceived notions. Various myths concerning the clean room have existed from the beginning. There are many beliefs, the facts of which have not been confirmed. Some of the theories published concurrently with the development of clean room technology have been rewritten using the data obtained through more than 20 years of experience. Theories and assertions not supported by confirmed data must be restudied. Qualitatively speaking, it will probably be in the development of a clean room that the flexibility of the down-flow-type and the energy-saving of the tunnel (Figure 3) will be found able to coexist, and low price materials will be developed.

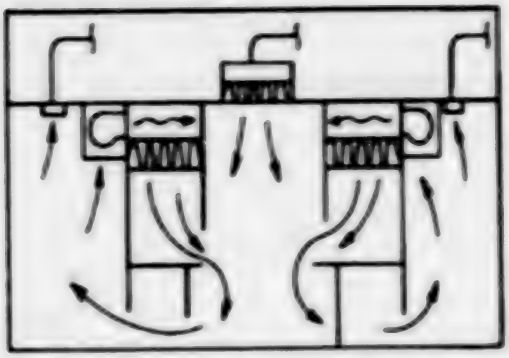


Figure 3. Tunnel-Type Clean Room

Discussion of Clean Room Method

1. Down-Flow-Type and Tunnel-Type

The representative clean room methods adopted by the semiconductor plants are roughly divided into the down-flow-type and the tunnel-type. Tables 2 and 3 show the characteristics and strong and weak points of the two methods. Generally, a large-scale clean room consists of a combination of these types, but the down-flow-type or the tunnel-type can be adopted according to the plant engineer's discretion. For example, the down-flow-type will be adopted if he places the most priority on flexibility in changing the production line in the future, and the tunnel-type if he places priority on the energy cost.

Recently, the clean room exploiting the strong points of both the down-flow and tunnel types has become the mainstream, and this combined room is divided into the two types--one is based on the down-flow-type to which the tunnel-type is added, and the other is based on the tunnel-type with the down-flow-type added.

Table 2. Characteristics of Down-Flow-Type

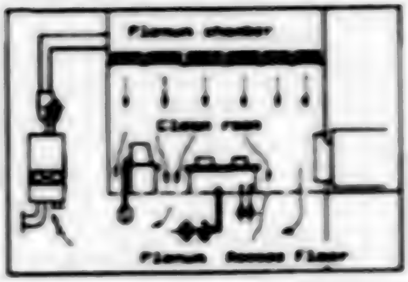
Item compared	Down-flow-type (whole vertical laminar flow type)
Air flow	
Cleanliness	Maximum cleanliness can be obtained in the entire room, however, it is affected, to some extent, by the congestion of devices or by the number of people in the room.
Temperature humidity	It is controlled by the room, and other methods are required for partial load control.
Flexibility	Change in process devices, change in layout, connection of utilities, etc., can be easily conducted. If the height of free access under the floor is sufficient, utility plumbing for the change can be done in advance, enabling the changing of a device in a very short time. Large-scale repair work cannot be conducted during operation.
Running cost	Circulating air quantity is large, and ventilation power cost is high. Ventilation power cost depends on the setting of the blow-off velocity.
Workability maintenance	Work is free for there are no partitions. Automatic conveyer system can be adopted easily. No problems in maintenance. Large space is good psychologically for workers.
Bad smell/ corrosion by chemicals	Effects of bad smells or corrosion produced from wet process on devices in the room are feared because no partitions exist. In case of accident, it will influence the entire process.
Safety	A gas accident, etc., will influence the entire process.
Vibration Withstand load	Problems exist with vibration and withstand load if raised floor is not strong enough. It is necessary to change floor material according to device installed.
Construction cost	Construction cost is high, and total construction cost will also be high.

Figure 4 is an example that is based on the down-flow-type, with partial use of the tunnel-type. The manufacturing device for photolithography processing is laid out freely in the large down-flow-area, placing emphasis on future changes and daily maintenance. On the other hand, air circulation with photolithography is separated by making the diffusion furnace system, whose amount of generated heat is large, a different system. The main reason involves not transferring the heat load disturbance to the stepper, aligner, etc., that require precise temperature control, and not letting the gas used in the diffusion system exert any influences. In addition, when influences, such as that of corrosion by the various acid vapors generated during the wet etching process, on the neighboring processes are taken into consideration, the wet etching process is established in the tunnel, which is made an independent air circulati-n system.

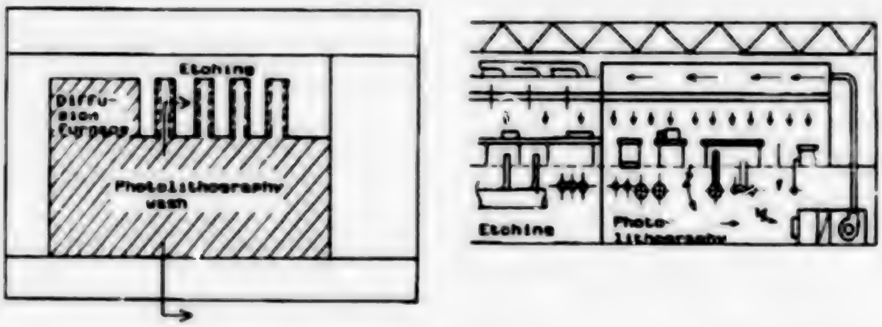


Figure 4. Combined Tunnel Method Based on Down-Flow-Type

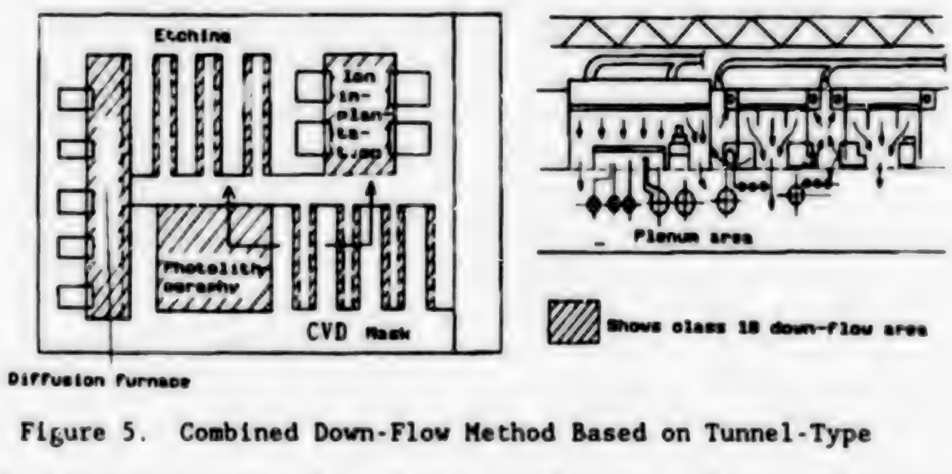


Figure 5. Combined Down-Flow Method Based on Tunnel-Type

Figure 5 shows an example of a clean room based on the tunnel-type with partial use of the down-flow-type. In the (hotoriso), the down-flow-type is adopted because the frequency of changing the manufacturing device is high, as mentioned above, and the uncovered wafer is moved in a wide area, etc. The down-flow-type is adopted during the diffusion process which requires the same high cleanliness for the entire area because the bare

wafer shuttles between the light etching on the opposite side of the diffusion furnace. Since the case in Figure 5 is basically the tunnel-type, different manufacturing processes are conducted in the separated independent air circulation, and the ventilation power is less than that of the down-flow-type due to the small laminar flow area.

2. Module-Type Clean Room by Ceiling Absorption

The space where the bare wafer is handled must be super clean, and a sufficient performance of this super clean space can be expected if a combination of the laminar flow and the ULPA filter is used. On the other hand, lowering the cost of semiconductor products is also an indispensable subject, and the reduction in the operating power expense of the laminar flow area, operated continuously throughout the year, is an especially important subject. Therefore, if a clean room method exists which makes the limited super clean space and the flexibility involving the exchange of manufacturing devices compatible, and its operating cost is low, it would be an attractive clean room method for the future. Figure 6 introduces a multipurpose clean room (Trade name: TCR-MP) developed by Takasago Thermal Engineering Co., Ltd., and, as is shown in the figure, all the equipment composing the clean room is modularized and housed in the ceiling.

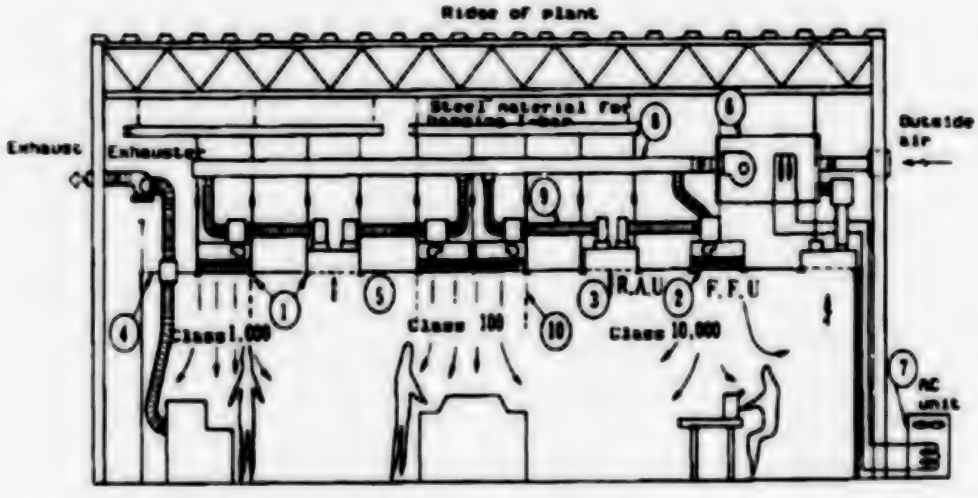


Figure 6. Structure of Module Method Clean Room by Ceiling Absorption

A laminar flow area of class 100 is shown in the center of Figure 6, and cleanliness of 0.1 μm, class 10, can be obtained when a ULPA filter is used and the wind velocity is maintained at about 0.35 m/s. Since all the equipment set in the ceiling, such as the fan filter unit, inlet port, and ceiling panel, is modularized and of the same size, the layout can be changed freely, the exchange of devices and the change in cleanliness can occur freely in the future.

When the production line is automated, only the products flow in the super clean space, while other work processes are set in the turbulent flow area of about class 1000. The operating power cost using this method will

become one-third to one-fourth that of the down-flow-type, and both the energy efficiency and area efficiency will become advantageous since the entire floor can be used for the layout of the manufacturing devices. The numbers (1) through (10) in Figure 6 indicate the following equipment.

(1) T-bar: Ceiling frame fabricated with solid-drawn aluminum material.

(2) Fan filter unit: Combined module of HEPA filter and a small fan.

(3) Absorption unit: Ceiling absorption return grill.

(4) Exhaust unit: Set in the ceiling above the equipment requiring exhausting, and connected to the exhaust duct.

(5) Ceiling panel: Panel of incombustible material that can be easily taken off.

(6), (7) Air conditioners: Air conditioning system is freely designed by the load characteristics of the production line.

(8) Air conditioning duct: Only the air for the regulation of temperature humidity is required.

(9) Flexible duct: Workability is made easy.

(10) Eyelid: Shapes the laminar air flow.

Energy-Saving of Clean Room

1. Cooling Load Characteristics of Semiconductor Plant Clean Room

No matter how high the required cleanliness and performance is, energy-saving is an important point in clean room design for semiconductor plants in Japan When planning energy-saving measures, the breakdown of the electricity consumption must be determined first, but marked features exist in the cooling load characteristics of the clean room of the semiconductor plant. Figure 7 is the cooling load list of a semiconductor plant, with the outside air load, fan motor, and heat generation of the manufacturing devices occupying 90.5 percent of the entire cooling load. Although the order of the top three items in the cooling load of the semiconductor plant changes with the kind of product and manufacturing devices to be installed, there is no change in the fact that these three items occupy about 90 percent of the total load. In short, the heat transfer, lighting, and heat generated by the human body, comprising the main cooling load of an office building, do not reach even 10 percent of the entire cooling load, therefore, it cannot be an important factor in the selection of coolers.

The cooling load of these top three items is automatically determined by the selection of other manufacturing devices and the type of the clean room. If the manufacturing device is chosen, the amount of exhaust required is determined by the specifications of the device and, at the same time, the amount of heat generation is indicated.

Attention must be paid to the amount of heat generated by the manufacturing device. The devices with the largest heat generation include the electric furnace, such as the diffusion furnace, with the capacity of the electric heater equipped with these devices and the amount of electricity consumed during the stationary state-differing by a large margin. Although the actual load factor is assigned 0.4 in Table 4, this factor can be large, as the selection of the refrigerator depends on it.

Table 4. Breakdown of Cooling Load

Load items	Cooling load (kcal/hr)	Percent
Outside air load	1,080,000	38.0
Air blower	1,060,000	37.2
Manufacturing device load*	440,000	15.5
Structural body heat transfer	138,000	4.9
Lighting load	62,000	2.2
Human body load	62,000	2.2
Total	2,842,000	100.0

*Calculated assigning the manufacturing device load factor a value of 0.4.

Generally, this value is believed to be around 0.2, but it is necessary to make sufficient arrangements with the engineers involving the plant facilities and processing regarding this point. According to past experiences, the capacity of the refrigerator tends to be too large, while it may be said that there have been almost no cases in which the capacity was too small.

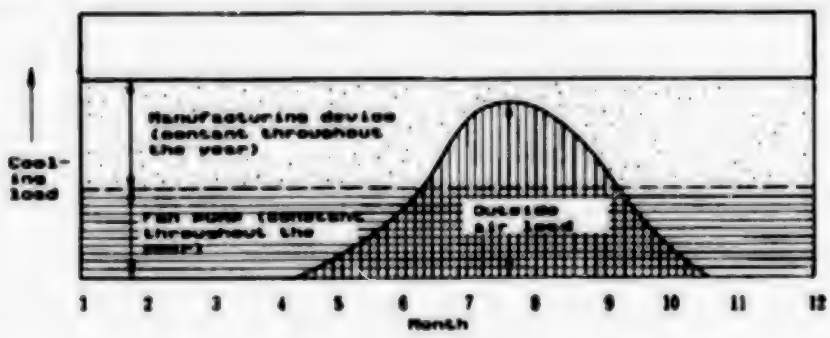


Figure 7. Annual Change of Cooling Load

Figure 7 shows the cooling load indicated in Table 4 as it occurs throughout the year. It must be noted that the outside air load is the maximum value at the peak, but the load is smaller than that of the other

two items when viewed throughout the year. It can be said that it is most effective to take energy-saving measures for the cooling loads of these top three items in the clean room of a semiconductor plant while, on the other hand, no effects can be expected from the other items.

2. Examples of Energy-Saving Measures

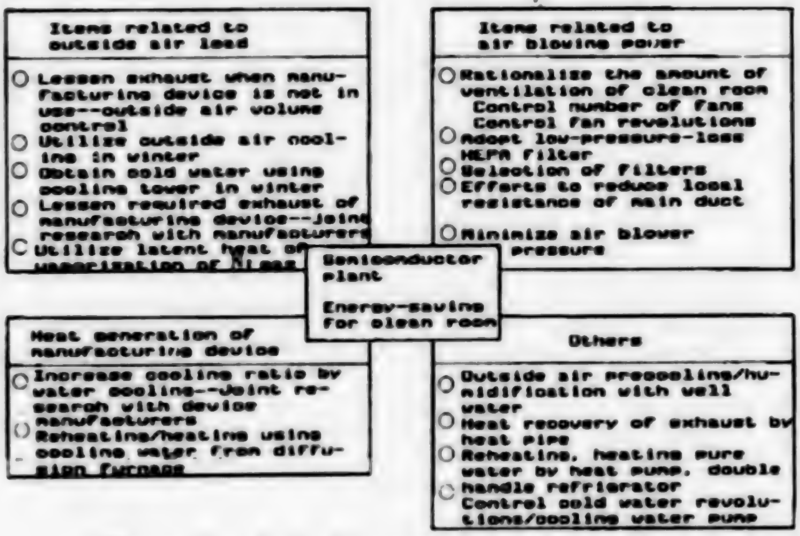


Figure 8. Main Energy-Saving Measures

Figure 8 presents a list of the energy-saving measures applicable to the items indicted in Figure 7. On the whole, it can be said that there is a strong tendency for the cooling load of the clean room of a semiconductor plant to be determined by the specifications of the manufacturing device. Therefore, the specifications of the manufacturing device, or the relationship between the manufacturing device and the air conditioning/exhaust, must be taken into consideration in order to effectively reduce the cooling load, that is, the operating power, e.g., the methods for reducing the amount of exhaust of the manufacturing device, the methods for cooling the heat generating devices when water does not disperse the heat in the clean room, etc. For this purpose, the three parties, including the semiconductor device manufacturers, the plant engineers, and the clean room design and construction companies, must work together. Even the clean room cannot be excluded from the targets of the age, which have been emphasizing energy saving lately, and the three parties must conduct joint research. Figure 9 presents the contents of each item indicated in Figure 8 as applied to the profile of the clean room of a semiconductor plant for a better understanding.

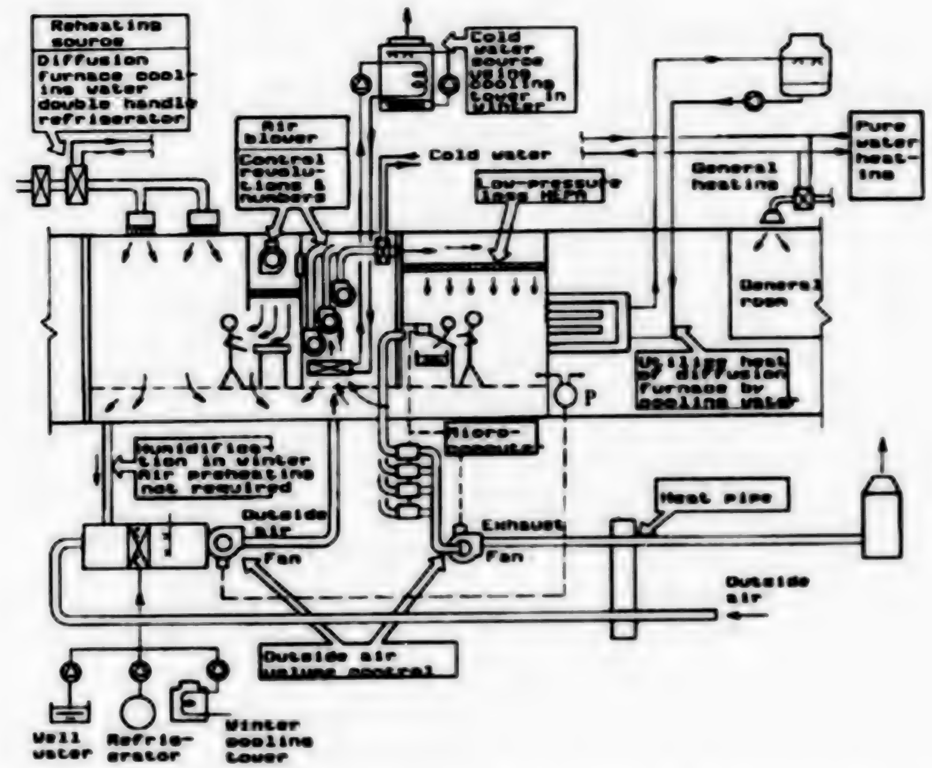


Figure 9. Energy-Saving Measures for Clean Room of Semiconductor Plant

20155/9365

New Long-Term Nuclear Power Development Plan Explained

Nuclear Development Plan Revised

43062520a Tokyo PUROMETEUSU in Japanese Nov 87 pp 20-22

[Article by T. Imamura, Atomic Energy Bureau, Science and Technology Agency]

[Text] **Preface**

With the 21st century now in view, the Atomic Energy Commission announced a new long-tern nuclear power development and utilization plan on 22 June. The new plan sets out the main guidelines for nuclear power development and utilization up to the year 2000 together with promotional measures.

1. Background of Revised Long-Term Plan

The situation surrounding Japan's nuclear power development and utilization has undergone great changes since 1982 when the previous long-term plan was formed:

(1) The world has moved toward the so-called age of internationalization.

(2) Supply-demand relations have eased worldwide.

(3) The importance of nuclear safety has been recognized anew, motivated by the accident at the Chernobyl nuclear power plant.

As a result of the progress in nuclear power development and utilization, it has become necessary to tackle new tasks such as:

(1) Complete the plan to commercialize the nuclear fuel cycle business, which has already taken concrete shape.

(2) Map out a fast-breeder reactor development plan based on the prototype reactor "Monju."

(3) Give due consideration to the movements aimed at new departures in nuclear fusion research and development.

(4) Review nuclear power in light of the science and technology policy in order to enhance the effects in both areas of nuclear power technology and other advanced technologies.

Nuclear power development and utilization in Japan has reached the 30-year mark and its future direction together with the way it should be carried out needs to be clarified.

Therefore, this new long-term plan, taking advantage of this occasion to return to the starting point of nuclear power development and utilization, explains its significance and shows the way it is to be carried through by setting basic promotional targets for the future.

2. Significance and Basic Targets

The primary significance of nuclear power development and utilization at present, as shown in the long-term plan, is that nuclear power is a form of energy that can be produced through intensified high technology. Thus technological capabilities can contribute to the solution of global energy problems. The second point is that nuclear power research and development is expanding and advancing into innovative areas. Thus the promotion of nuclear power research and development becomes a tractional force for raising the levels of the wide range of science and technology that constitute nuclear power technology.

The new long-term plan calls for pursuing the potentialities of nuclear power and aims to create a social foundation for nuclear power in the 21st century. Its two major tenets are "hold fast to peaceful utilization" and "secure safety." Also, the new long-term plan has set the following three principal targets for the promotion of nuclear power development and utilization in the future:

(1) To position nuclear power as the principal energy source that will help the country to overcome its vulnerability to the energy supply structure. This end can be achieved by promoting the development of nuclear power while striving for qualitative improvements in terms of safety, reliability, and economical efficiency.

(2) To promote creative research and development in the nuclear area and to take advantage of the next-generation of creative scientific technology by promoting collaboration and exchanges with scientific technology in other areas.

(3) To make a positive contribution to international society together with the most advanced countries in the West in the area of nuclear power development and utilization while discharging Japan's international responsibilities as a nation that promotes the peaceful use of nuclear power.

3. Important Tasks in Promoting Nuclear Power Development and Utilization

The new long-term plan summarizes the basic concept underlying the measures to promote nuclear power development and utilization in line with the main targets in the following six areas. This article provides an outline rather than the full details of these areas:

(1) Safety Enhancement

The safety of nuclear power facilities in Japan has basically been established. The evaluation of the accident at the Chernobyl nuclear power plant and a review of the present safety measures in Japan have substantiated this conclusion. Nevertheless, reinforcing safety measures and international cooperation in the area of safety will continue to be promoted in the future. At the same time, efforts will be made to conduct research on safety and security and to educate workers to cope with new aspects of nuclear power development and utilization in the future.

(2) Promotion of Basic Line of Nuclear Power Generation

Japan maintains a basic line of "reprocessing and recycling," under which spent fuel is reprocessed and the plutonium and uranium recovered from this process are used to ensure the effective use of uranium resources and to improve the stability of the supply of electricity generated by nuclear power. Development is underway to establish a nuclear fuel cycle and to use plutonium for fast breeder reactors. The scale of development of nuclear power generation, which offers a framework for implementing this line, is estimated at least at 53 million kw (about 40 percent of all electric energy generated) in the year 2000, taking into account the recent slowdown in the growth of power demand. A long-term forecast, however, predicts that it will exceed 100 million kw (about 60 percent of total electric energy generated) in 2030.

(3) Promotion of R&D in Creative and Innovative Areas

Nuclear research and development is enhanced by stressing these frontiers of nuclear power R&D that are expected to produce far-reaching effects on general scientific technology through greater technological innovation resulting from the search for technological seeds and from the accumulation of scientific research and development, and by promoting collaboration and exchanges with research and development efforts in other areas. With such concepts in mind, basic research activities are strengthened and leading projects such as nuclear fusion are promoted. At the same time, common technology in the nuclear power area, regarded as basic technology, is promoted on a priority basis.

(4) Active International Posture

Japan's international cooperation in the nuclear power area has heretofore been characterized by its insistence on carrying out its own nuclear development. In the future, however, Japan will seek to develop an active international posture. Then, as a sincere promoter of the peaceful

utilization of nuclear power, Japan will make efforts to maintain and strengthen the safeguard system under the Nonproliferation Treaty and the IAEA, and to win greater international confidence in adhering to nuclear nonproliferation.

(5) Strengthening the Foundation of Nuclear Power Development and Utilization

It is necessary to firmly establish Japan's technological basis in order to ensure a steady advance in nuclear power development and utilization. It is necessary for this purpose to establish a state-people cooperation system on the basis of accumulated technology. From this perspective the R&D system will be consolidated and the nuclear power industry's foundation strengthened.

(6) People's Understanding and Cooperation

Since it is quite necessary to obtain the people's understanding and cooperation in order to promote nuclear power development and utilization, this will be carried out by seeking to understand their position on it and by living up to their expectations.

Closing Remarks

Japan's nuclear power development and utilization has advanced from the stage where it had much to learn from the advanced countries to the stage where it is able to improve the quality of nuclear power and to pursue its new potentialities together with them. Since the long-term plan envisages further progress in nuclear power development and utilization, it is important for Japan to promote nuclear power development and utilization more actively from a global standpoint as we approach the 21st century.

Table. Long-Term Nuclear Power Development and Utilization Plan

Item	Present status	Plan
Nuclear power generation		
Scale of nuclear power generation (equipment capacity)	27.88 million kw	At least about 53 million kw in the year 2000 Over 100 million kw in 2030
(Percentage of all electric energy generated)	28% (FY 1986)	40% in 2000 60% in 2030
Nuclear fuel cycle		
Uranium enrichment	PRNFDC's prototype plant (100 tSWU in FY 1985)	New commercial plant (1,500 tSWU) starts up around 1991

[Continuation of Table]

Item	Present status	Plan
Reprocessing	PRNFDC's Tokai plant (74 t in FY 1985)	First private plant (800 t/year) starts up around mid-1990s Second private plant starts up around 2010
Disposal of low-level radioactive waste		Disposal starts around 1991. Quantity disposed of will reach finally about 3 million drums of 200 w capacity
Plutonium utilization		
Fast breeder development	"Joyo" experimental reactor with thermal output of 100,000 kw	"Monju" prototype reactor (280,000 kw), reaches criticality in 1992
		Construction of experimental reactor starts late in 1990
		Plutonium utilization technology system is established between 2020 and 2030 by using fast breeder reactors
Plutonium thermal reactor	Small demonstration unit (PWRI, BWRI)	Full-scale use (about 10 LWR units) late in 1990s
Advanced thermal reactor development	"Fugen" prototype reactor (165,000 kw)	Oma demonstration reactor (606,000 kw) starts up in mid-1990s
Nuclear fusion	Critical plasma experimental equipment	Construction of large-scale equipment for next term starts in first half of 1990s
R&D funds		About ¥7 trillion cumulative to 2000 from 1987
Nuclear power-related researchers and workers	55,000	About 75,000 in 2000

LWR, Fuel Cycle

43062520a Tokyo PUROMETEUSU in Japanese Nov 87 pp 38-39

[Article by A. Yuki, chief of the Nuclear Fuel Division, Atomic Energy Bureau, Science and Technology Agency]

[Text] 1. **Preface**

Chapter 2 of the new long-term nuclear power development and utilization plan provides for a future basic policy under the heading of "Nuclear Power Generation and the Nuclear Fuel Cycle" with regard to light water reactors, the leading source of nuclear power generation, and the nuclear fuel cycle, which supports their operation.

This article will present important future tasks involving light water reactors and the nuclear fuel cycle in conjunction with the long-term plan.

2. Light Water Reactors

The new long-term plan considers the light water reactor to be "the reactor that will continue to lead Japan's nuclear power generation for a long period." Additionally, it directs not only that "light water reactor technology be further upgraded" in the future, but also that "research and development be positively tackled by stressing its fundamentals, aiming at greater safety, reliability, and economic efficiency." The objects of such fundamental research and development include "high conversion light water reactors" and "inherent safety." Future tasks in such areas are to conduct basic research on nuclear and hydrothermal power properties at the Japan Atomic Energy Research Institute, etc.

3. Uranium Enrichment

Japan, which presently depends on the United States and France for its entire supply of enriched uranium, intends to improve its domestic supply ratio through the local production of enriched uranium using a centrifuge separation method. "About 3,000 t SWU/year after the year 2000" is set as the national production goal. A plan to construct a commercial plant (final production scale is 1,500 t SWU/year) in Rokkashio village, Aomori Prefecture, is to be implemented with a view to building and operating a prototype plant (200 t SWU/year).

With respect to uranium enriching technology using new materials in high performance centrifuges--which aims at using new technology to improve the economic efficiency of uranium enrichment--research and development of both the atomic and molecular methods is to be conducted. The new long-term plan stipulates that "the way to push this program forward in the future will be reviewed as required beginning around 1990 based on an examination of the results obtained by that time. With respect to chemical uranium enrichment technology, it also provides that "this technology will be evaluated at an appropriate time while keeping an eye on its future development."

Thus, with regard to the development of new uranium enrichment technology, it will be necessary to evaluate each technology at an appropriate time in the future.

4. LWR-Spent Fuel Reprocessing

Spent fuel reprocessing is important both from the viewpoint of the effective use of uranium resources and of the proper management of the radioactive waste contained in spent fuel. The new long-term plan provides that "in principle reprocessing is to be undertaken domestically" and that "spent fuel in excess of domestic reprocessing capacity is to be properly stored and managed pending reprocessing." It also stipulates that "foreign consignment of reprocessing will be carefully dealt with by taking into consideration conditions both at home and abroad."

As concrete steps, the Tokai reprocessing plant, which is now in operation, is to continue its operation on a stable basis and the construction and operation of the first private reprocessing plant (reprocessing capacity of 800 t/year) in Rokkasho village, Aomori Prefecture, is to proceed smoothly with initial operation expected to begin around the mid-1990s. A second private reprocessing plant with greater economic efficiency secured by its own technology is also to be constructed, aiming at a startup date around 2010. Its aim is to promote synthesized technological development.

A future task is to establish a domestic reprocessing technology as soon as possible. For this purpose it is important to steadily assimilate foreign technology and it is also important for the private reprocessing enterprises--the Power Reactor and Nuclear Fuel Development Corp., the Japan Atomic Energy Research Institute, etc.--to conduct a number of essential tests that will be assigned to each of them. In this connection, another important future task is to review from a long-term perspective the status of the Tokai reprocessing plant.

5. Radioactive Waste Reprocessing and Disposal

With regard to radioactive waste reprocessing and disposal, formation disposal is the most important policy issue. The new long-term plan, which outlines a four-step procedure for carrying out formation disposal of high-level radioactive waste, stresses that the second stage represents an "important national project" and provides detailed measures for promotion.

The new long-term plan also indicates that disposing agents will be appointed by the government at an appropriate time during the second stage and that concrete measures will be elaborated to cover as soon as possible the expenses incurred by the government in disposing operations.

As future tasks it is important to clarify concrete research and development programs aimed at establishing formation disposal technology and technical conditions consistent with the geological environment of the land set aside for disposal and to concretely examine the measures to ensure disposing expenses.

Plutonium Use

43062520a Tokyo PUROMETEUSU in Japanese Nov 87 pp 39-41

[Article by T. Okazaki, chief, Power Reactor Development Division, Atomic Energy Bureau, Science and Technology Agency]

[Text] Japan, which is not abundant in uranium resources, has heretofore adopted a policy (reprocess/recycling line) of reprocessing spent fuel and again utilizing the recovered plutonium and uranium as energy resources.

However, the current environment does not lend itself to creating the conditions necessary for promoting reprocessing and recycling. First, the supply-demand situation of natural uranium has recently eased worldwide and, second, at the present level of technology plutonium utilization has considerable room for improvement in terms of economic efficiency, particularly when compared with uranium utilization by light water reactors. The second subcommittee of the Technical Committee of the new long-term plan has discussed plutonium utilization and the development of new types of power reactors for that purpose. An outline of its work is introduced below.

1. Maintenance of Reprocessing/Recycling Line

Despite improvements in the uranium supply in recent years, it is important to consider the following points in estimating the supply and demand of natural uranium:

(1) Economical mining feasibility is not in sight and the quantity available to Japan is limited.

(2) Mine development and production require a lead time of 10 to 15 years.

(3) Since resources of natural uranium will eventually be exhausted, there are possibilities of an undersupply and price hikes in the long run.

Japan should conduct steady development aimed at plutonium utilization for fast breeder reactors (FBRs) which is more advantageous than uranium utilization for light water reactors in terms of economic efficiency and safety, taking these points into consider. The continuance of plutonium utilization on a certain scale (even though not full-scale utilization by FBRs) is expected to contribute to stabilizing the prices of natural uranium and enriched uranium in the current era, predicted to last longer, of prevalent uranium utilization by light water reactors.

2. Plutonium Utilization Programs

(1) Since fast breeder reactors are capable of producing fissionable isotopes, as is generally known, full-scale utilization of FBRs could greatly reduce Japan's dependence on foreign supplies of uranium in the future. In order to bring FBRs into practical use it is essential that

they be competitive against light water reactors in terms of safety and economic efficiency. Their practical use is basically regulated by market mechanisms, which makes it difficult to predict exactly when they could be put to practical use. A forecast based on currently available data on uranium resources indicates that it will be necessary to have FBRs in practical operation no later than the year 2030 and to reduce the quantity of natural uranium required. Since it is advisable for Japan to implement the practical use of FBRs as early as possible, it should push the construction of the prototype reactor "Monju" as planned (criticality in 1992) and to steadily carry out the development of FBRs. It is necessary for the electric power utility to implement as a principal objective the project to construct a demonstration reactor (No 1) based on the initial FBR development results, aiming to begin construction in the latter half of the 1990s. It is also necessary to establish the FBR as a technological system competitive against light water reactors between 2020 and 2030 through the construction of one or two more demonstration reactors to accumulate operational experience.

(2) Plutonium Utilization by LWR, ATR

Plutonium can be used by light water reactors and advanced thermal reactors (ATRs), taking advantage of the following merits:

(1) The light water reactor does not require great changes in the design of existing atomic reactors.

(2) The advanced thermal reactor can effectively use plutonium.

Plutonium is primarily intended for full-scale utilization by FBRs in the future, but before then it will be necessary to acquire technology through the utilization of uranium in LWRs and ATRs.

(3) Reprocessing FBR-Spent Fuel

Reprocessing is the key to plutonium utilization. With respect to the reprocessing of spent fuel from light water reactors, the first private uranium plant with a capacity of 800 t/year, scheduled to start up around the mid-1990s, is being planned in addition to PRNFDC's Tokai plant. On the other hand, since the fast breeder reactor performs breeding functions, supported by reprocessing technology, the development of this technology and the reactor should be carried out in close conjunction with reprocessing technology. It is planned for the time being to establish basic technology and process engineering by using the hot test facility of an engineering scale and to concretize a pilot plant construction project, aiming at operational startup after the year 2000.

(4) MOX Fuel Processing

Since it is necessary to establish plutonium fuel manufacturing technology and its production system in order to develop plutonium utilization, there are plans to consolidate the fuel processing systems for plutonium utilization by light water reactors as well as the fuel processing system

for FBRs early in the 1990s while at the same time accumulating experience from the progress of the PRNFDC's Third Development Office in manufacturing fuel for "Monju."

Achieving plutonium utilization is the ultimate goal and the benefits from doing so will be great. To achieve this goal unfailing research and development efforts and a heavy investment are indispensable. Therefore, in addition to the efforts made by the sectors concerned, the joint efforts of government and people should be exerted positively toward the practical use of plutonium in line with the new long-term plan.

Research, Development

43062520a Tokyo PROMETEUSU in Japanese Nov 87 pp 41-42

[Article by N. Teraoka, Technology Development Division, Atomic Energy Bureau, Science and Technology Agency]

[Text] 1. **New Tasks**

Nuclear power research and development to date has concentrated on achieving a stable supply of energy and early commercial utilization. However, it will be necessary in the future to elastically cope with diversified, sophisticated demands concerning nuclear power. These include improving the reliability and economic efficiency of nuclear power facilities; expanding its applications, such as the use for power source; establishing the nuclear fuel cycle; promoting radiation utilization; and reducing exposure doses.

Since nuclear power technology is a composite technological system consisting of various high technologies, its advancement will likely play the role of motive power for developing scientific technology in favor of Japan aiming at the establishment of a state program on the basis of scientific technology.

It is necessary for Japan to fulfill its obligations as one of the world leaders in nuclear power research and development by contributing to international society through the creation of innovative technologies and new concepts and through the revitalization of nuclear power research and development

2. **Basic Direction**

In order to accomplish these tasks it is necessary not only to improve existing technologies but to come up with creative nuclear power technology. On the strength of the achievement of these goals, the current manner of research aiming at "catching up" with the West can be shifted to "creative research."

Also, systematic research and development will be conducted by making the most of the potential for research and technical information available at the Japan Atomic Energy Research Institute, the Power Reactor and Nuclear

Fuel Development Corp., national research institutes, universities, and private companies, while making the best use of the character of each research institution.

3. Concrete Measures

It is important that basic research, basic technology development and research on leading projects be conducted effectively by promoting harmony and close exchanges.

(1) Strengthening Basic Research

Since basic research is expected to produce epochal results from a researcher's unfettered thinking, the independence research institutions is a highly respected principle with regard to the selection of research themes. Examples of these themes include research on the physical theory of heavy ion and high-energy corpuscular beams and their interactions, analysis of the burnup behavior of fuel, hydrothermal dynamic behavior and the design of reactor cores.

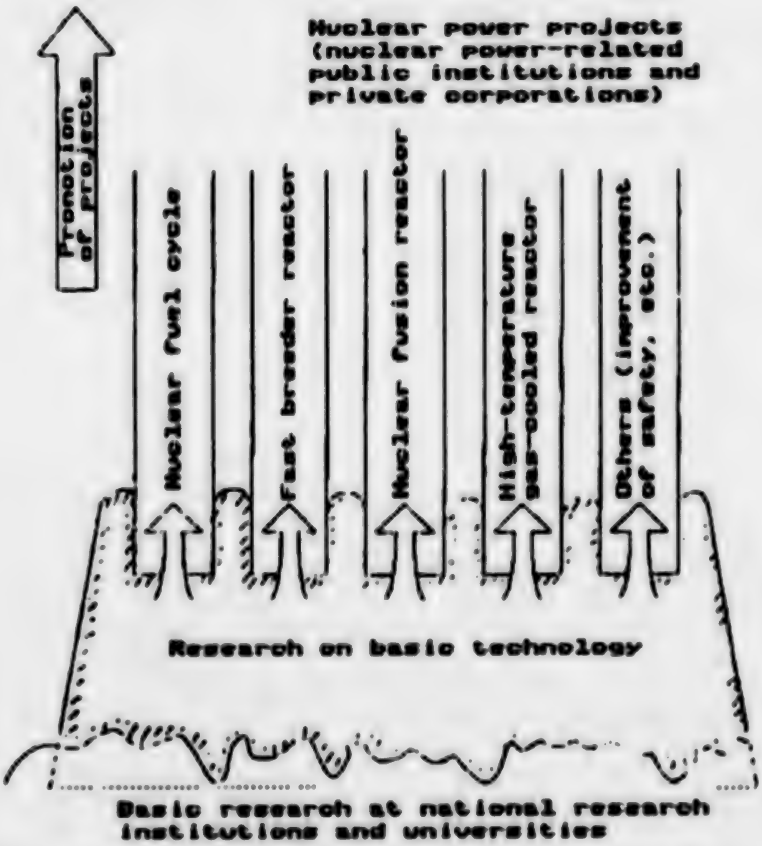


Figure 1. Necessity of Basic Technology Development

(2) Promotion of Basic Technology Development

An examination of the technological themes dealing with the needs of nuclear power over the next 12 years reveals that several technologies offer common bases for a number of nuclear power projects currently underway. These are:

1) Technology concerning the materials used for the equipment and pipes of nuclear power facilities.

2) Technology to provide intelligent functions for nuclear power plant control, nuclear reactor accident analysis, and remote waste control.

3) Technology concerning lasers, which are widely used in the nuclear power sector for such purposes as adjusting the valence of nuclear fuel substances, reprocessing and inertial nuclear fusion.

4) Technology to evaluate radiation risks--it is necessary to acquire more information about national safety and to reduce such risks.

The systematic and intensive promotion of such basic technologies will make it possible to upgrade and diversify nuclear power technology. It is expected that the accumulation of the results of basic technology development efforts will create innovative technologies that will have a great impact on the present nuclear power technology system.

(2.1) Nuclear Material Technology

With respect to the development of materials for use in nuclear power plants, radiation resistant materials and materials capable of reducing radiation will be developed, focusing in particular on their properties in a radioactive environment--neutron radiation in particular--with the aim of introducing the latest material design techniques. Additionally, development aimed at upgrading technologies for analyzing materials and evaluating the reliability and safety of materials will be carried out.

(2.2) Artificial Intelligence Technology for Nuclear Power

Research and development of checking and repairing robots capable of intricate judgment and motion in narrow radioactive places by making the best use of the latest artificial intelligence technology and operation monitoring systems with the good man-machine interface will be conducted.

(2.3) Laser Technology for Nuclear Power

Research and development in the area of laser technology is expected to bring about epochal technological innovations in the fields of nuclear fuel enrichment, spent fuel reprocessing, radioactive waste processing and nuclear fusion. Thus, it is expected that existing lasers will eventually be upgraded to make their wavelengths shorter, variable, and highly repeatable. Also, the development of utilization process technology and

research on laser physics and chemistry, which constitute its basis, will be conducted.

(2.4) Technology To Evaluate and Reduce Radiation Risks

It is important to conduct research on the biological effects of radiation in order to further increase our knowledge and information about national safety. This in turn will foster the development of radiation evaluation and reduction technology that incorporates the latest approaches, such as life science.

(3) Promotion of Leading Projects

Leading projects such as research and development in the area of nuclear fusion and high-temperature engineering will be carried out with the specific goal of obtaining a stable energy supply. However, since elemental technologies to back up these projects are mostly high technologies, the promotion of these projects is expected to play a seminal role in the development of advanced technologies. The feasibility of other new projects having leading roles in developing scientific technology, including small- and medium-size safe reactors, will be widely examined.

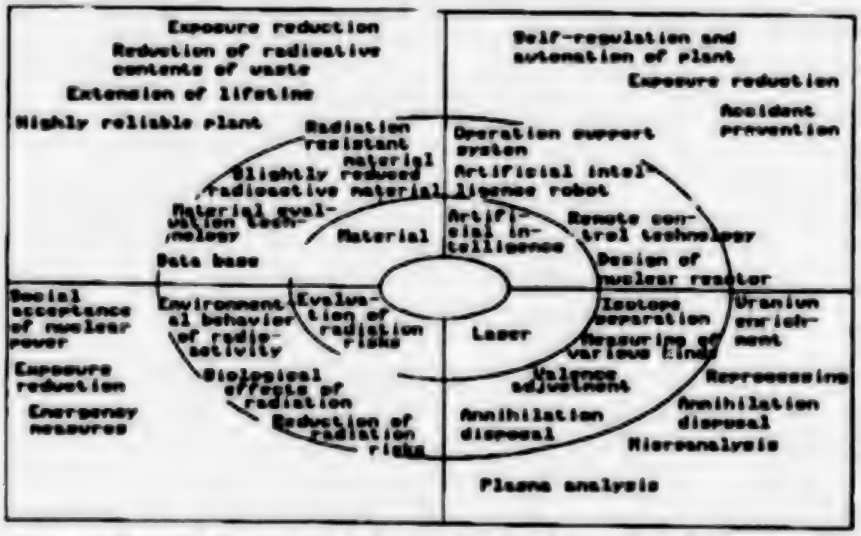


Figure 2. Evolution of Basic Technology Development

International Posture

43062520a Tokyo PUROMETEUSU in Japanese Nov 87 pp 43-45

[Article by K. Mamiya, chief, Research and International Affairs Division, Atomic Energy Bureau, Science and Technology Agency]

[Text] 1. Background

Japan's international posture in the area of nuclear power--including nuclear power generation, the nuclear fuel cycle, the development of a new

type of power reactor and research and development at the frontiers of nuclear power--was one of the points at issue at the latest review of the long-term nuclear power development and utilization plan. The results of the discussion on Japan's international posture are summarized as follows.

2. Changes in Circumstance

Japan has until now made international commitments in the field of nuclear power primarily to supplement its own technology or to comply with the requests of foreign countries.

The following changes in the international environment and the advances in its nuclear power development have forced Japan to change its international posture:

(1) Japan represents 10 percent of the world GNP and its technology has reached a very high level.

(2) Japan's nuclear power technology has reached a level comparable to that of other industrialized countries including safety and reliability technologies. It will be necessary in the future for Japan to positively tackle tasks that all countries face in dealing with radioactive waste and dismantling nuclear reactors.

(3) It is important for Japan to actively make efforts to upgrade its nuclear power technology, including development in unknown areas, and to make the results of its efforts available to all mankind.

(4) It is generally expected that Japan, which has an active and firm nuclear power development plan including the practical use of plutonium utilization systems, will serve as the driving force for worldwide nuclear power development and utilization efforts.

(5) As an advanced country in the field of nuclear power, Japan is expected to play a leading role in stabilizing the international nuclear power environment.

3. Future Stance

Given these change in the international environment, Japan's role in the field of nuclear power is to act as a prime mover in the future development and utilization of nuclear power together with leading Western countries and to contribute to the solution of humanistic problems such as further improving the energy supply-demand situation throughout the world and to bettering the international environment concerning nuclear power safety and nuclear nonproliferation. It is important that Japan assume an active international posture and discharge its responsibility by carrying out such missions.

4. Basic Goals

There are three basic targets for Japan if it is to make a positive international contribution in the field of nuclear power.

The first goal is to pursue common world interests. To deal with various problems that all countries confront in promoting nuclear power development and utilization--such as the reprocessing and disposal of radioactive waste and dismantling nuclear reactors--Japan should promote creative research and development from a long-term viewpoint to produce new technology and knowledge and offer the results for the peaceful utilization of nuclear power in order to serve the common interests of all countries.

The second target is the effective international use of R&D resources. Due to global change in circumstance, such as the arrival of the low-growth age and the expansion of R&D projects, restrictions on R&D resources in terms of funds and brains have become increasingly important. Under these circumstances, to carry through the large-scale R&D projects now underway in all countries will require international cooperation in order to overcome shortages of R&D funds.

The final target is to promote an international environment conducive to the peaceful utilization of nuclear energy. In order to step up nuclear power research and development not only in Japan but around the world it is essential that the world nuclear nonproliferation system function soundly and that nuclear safety be ensured internationally.

5. Steps To Achieve Basic Goals

The positive steps Japan will take to promote international cooperation in the future in order to attain such basic goals as the pursuance of common interests, the effective utilization of R&D resources in all countries and improving the international environment are as follows:

Cooperation with industrialized countries:

Since it is necessary to join hands with the industrialized countries to serve common world interests, Japan will seek to advance international cooperation in the area of elemental technology where Japan has achieved a high technological level by taking the initiative and performing a leadership role.

•Stepping up cooperation in exploring basic nuclear fusion technology and examining the possibilities of participating in the joint design and construction of equipment after the next term.

•Extensive international cooperation aimed at improving the economic efficiency of fast breeder reactors and cooperation concerning elemental technologies in regard to the safety, fuel and materials of fast breeder reactors.

•Cooperation concerning safety measures, reprocessing and disposal of radioactive waste and dismantling nuclear reactors.

•International cooperation with regard to public acceptance.

•Cooperation in creative and innovative R&D including high-level utilization of radiation.

Cooperation with developing countries:

With respect to cooperation with developing countries, including the newly industrialized countries, it is important that cooperation begin at the initial stages of their nuclear power development and utilization plans in accordance with the levels of their nuclear power development, taking into consideration the conditions of those countries and emphasizing the consolidation of their bases of research and technology with a view to raising their levels of development.

Cooperation with neighboring region

The neighboring region, which is in close contact with Japan geographically and economically, has many common tasks in the nuclear power area. These include the utilization of radiation and research reactors, introduction of a nuclear power generation system and safety measures.

Japan will participate at the planning stage to make the best use of limited R&D resources, including funds and personnel from the region, and will step up cooperative efforts by involving the entire region. At the same time Japan will act to secure regional consensus and will seek to play a leading role in raising the levels of nuclear power technology for the entire region. Such efforts will include:

•Holding regional meetings.

•Promoting the concept of regional centers.

•Examining joint R&D on nuclear power reactor systems suitable for the region.

Cooperation with international organizations

At such international organizations as the IAEA and OECD-NEA, Japan has so far maintained a reserved stance given the size of its budgetary contribution (made in proportion to the GNP of member countries). In the future, however, Japan will actively participate in the activities of these organizations in an effort to create an international environment that will facilitate the promotion of the peaceful utilization of nuclear power and in which the common problems that face all countries can be solved. At the same time, Japan will make an effort to deepen international understanding of its nuclear power activities through its activities at these international organizations:

•Invitations to international conferences.

•Increasing the number of qualified staff dispatched to international organizations.

•Making contributions to activities closely connected with Japan.

Internationalization of domestic system

Strategic plans for Japan to fulfill its international commitments will be formulated and its domestic system will be adjusted to effectively implement the plans:

•Internationalization of R&D institutions including the Japan Atomic Energy Research Institute and the Power Reactor and Nuclear Fuel Development Corp.

•Preparation of accommodations for foreign researchers.

•Developing an internationalist cadre by stationing the same personnel at international organizations over and over again.

Posture toward nuclear nonproliferation

Japan which has consistently promoted the peaceful utilization of nuclear energy based on the doctrine of nuclear nonproliferation, will continue its posture of maintaining and strengthening the NTP-IAEA safeguard system; clarifying its active commitment to nuclear nonproliferation; deepening confidence in its commitment; and effectively and efficiently implementing IAEA safeguards:

•Strengthening the internal safeguard system.

•Consolidating the nuclear material protection system.

6. Closing Remarks

The promotion of a positive international posture in the nuclear power area is not only an obligation for Japan as an advanced nation in the field of nuclear power, but is indispensable for the development and utilization of nuclear power worldwide. In order to achieve these objectives through continued efforts it is necessary to formulate strategic plans and to implement them effectively. To this end necessary functions should be strengthened through cooperation between the government agencies concerned, centering around the Atomic Energy Commission, and through cooperation between the government and the people. It is also necessary to steadily promote the internationalization of research institutions by preparing accommodations for foreign researchers and by fostering an international perspective.

20110/9365

- END -

END OF

FICHE

DATE FILMED

6 June 1988